PRECONCEPTIONS IN MECHANICS: LESSONS DEALING WITH STUDENTS' CONCEPTUAL DIFFICULTIES

Pre-production Manuscript for Second Edition

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A complete bound edition in an easy-to-read format containing all nine units and CD Rom with customizable student materials is available from AAPT at:

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First Edition, 1994 by Charles W. Camp and John J. Clement

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A large number of people contributed to the production of these lessons. The bridging analogies strategy was proposed by J. Clement. The relative motion lessons were initially designed by C. Camp. A prototype of the book-on-the-table lesson (in unit I) and elements of the inertia lessons were designed by J. Minstrell. Pilot tutoring sessions to evaluate lesson strategies were conducted by D. Brown. Other lessons were authored by a team of researchers and teachers consisting of C. Camp, J. Clement, K. Schultz, D. Brown, K. Gonzales, J. Kudukey, J. Minstrell, M. Steinberg, and V. Veneman. Classroom trials of the lessons were conducted by C. Camp, V. Veneman, and J. Kudukey. Classroom observations were made by D. Brown, J. Clement, K. Gonzales, K. Schultz and M. Steinberg. Evaluations of lessons were conducted by D. Brown, K. Gonzales, and J. Clement. Tapes of the lesson trials were reviewed by the entire authoring team leading to implementation of revisions. At least three trial years and two revision cycles were conducted for each lesson. Lessons were typed by D. Freeman, D. Forrester, and D. Litterer, and drawings incorporated by D. Cain, T. Hayword, J. Monaghan, B. Young, and A. Zietsman.

Second edition changes were primarily based on the teaching experience of Charles Camp, John Kudukey, and Valerie Veneman. Second edition editing was done with the assistance of Lynn Stephens, Kristen Forrelli, Megan Graham, Stanford Chiu, and Elyse Horowitz.

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Preface to the Second Edition

Changes in the second edition have been primarily based on the teaching experiences of Charles Camp, John Kudukey, and Valerie Veneman. Suggestions from other teachers and more strategies from recent teaching materials have also influenced this edition.

In this edition we have chosen to emphasize the nature of the friction, tension and gravity concepts as forces by using the terms friction force, tension force, and gravitational force throughout the book. This change was also influenced by our concern about the need to help students distinguish between the concepts of force and inertia. The inertia units have been reduced in length while retaining the most effective parts of these units.

Other changes have included switching the order of units 6 and 7. While we feel there was a significant advantage to the early arrangement of revisiting the gravitational force concept in a spiral fashion, we also think that many teachers will be more comfortable with the sequence in this edition. Certainly both sequences for chapters 6 and 7 are possible as indicated by the suggested teaching sequence diagram in the Introduction.

Many smaller adjustments have been made to give teachers advice about the importance of carefully introducing demonstrations at the proper time and drawing out vital points during critical discussions. The use of voting during each lesson has been examined and carefully adjusted. All units have been revised for clarity, and more alternative strategies and references to updated external resources have been offered in a number of places.

We hope that these materials will continue to challenge student thinking in a cheerful and positive way in order to help them make sense of these fundamental physics concepts.

Charles Camp and John Clement

June 2008

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LESSONS DEALING WITH STUDENTS' CONCEPTUAL DIFFICULTIES

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INTRODUCTION

The units listed in the table of contents of this book are areas where students have exhibited qualitative preconceptions--ideas that they bring to class with them prior to instruction in physics. Research has shown that certain preconceptions conflict with the physicist's point of view in many circumstances. It has also shown that some of these conflicting preconceptions are quite persistent and seem to resist change when using normal instructional techniques. The motivating idea for this book is to provide a set of lessons that are aimed specifically at these particularly troublesome areas and that use special techniques for dealing with them. Ideas in the lessons can be used to supplement any course that includes mechanics.

When used in a standard high school course, the lessons should require about one 50 minute period each. They have been tested in classes for both standard, upper, and lower level high school physics students. In this second edition the lessons have been extensively revised on the basis of classroom observations and teacher recommendations over a 12 year period. Many of the lessons are adaptable to college level courses as well.

General Goals

Several general goals guided the design of these lessons:

Content Goals:

- To help students understand fundamental ideas where there are common preconceptions differing from the physicist's view
- To help students build concepts that make sense to them by starting from useful intuitions
- To help students construct explanatory models--the causal mechanisms that give rise to physical effects. These embody important knowledge that goes beyond rules describing patterns in observations
- To make connections to other physics concepts and to familiar everyday phenomena

Process Goals: To encourage students to:

- Actively participate in intellectual discussions
- Decide whether ideas make sense to them and work to make ideas make sense
- Generate analogies and explanatory models
- Criticize and evaluate explanatory models and analogies by formulating arguments for and against them
- Extend concepts to new applications

General Teaching Strategy

Dealing with Preconceptions by Using Analogies

Many preconceptions that pose difficulties are not simply random errors; rather, they are often reasonable ideas, but based on assumptions that conflict with the scientist's view. Nor are they simply due to inattention or failure to remember key ideas. They can persist even in the face of concerted teaching to the contrary. To help a student learn physics in areas where there are persistent preconceptions, these lessons use a number of special strategies. Most lessons are built around a target problem (a problem in which a preconception that is not consistent with the physicist's view is drawn out in many students). Another strategy is the use of anchoring analogies or examples--situations where a student's intuitions are in agreement with the physicist's view. Such an intuition can be developed as a rival to a conflicting preconception and eventually predominate as an idea that makes sense in physics.

It is suggested that the reader examine Lesson 1 of Unit #1 on static normal forces as an example at this point. The concept diagram in Figure 1.2 of that lesson shows a number of the instructional strategies to be utilized in this book. The starting point is a discussion of a target problem followed by a discussion of an anchoring example.

When students have trouble with a target problem, many of the lessons shift to a more easily comprehended anchor situation. They then ask students to think and talk about the similarities and differences between the target problem and the anchor. Subsequent examples are designed to bridge the conceptual gap between the intuitively understood anchor and the target problem; specifically, the lessons consider bridging examples that are conceptually intermediate between anchor and target and ask students to think and talk about the similarities and differences between these and the anchor and target problems (see Figure 1.2 in Lesson 1). These examples help students extend the correct conception back to the target problem.

Opinion Surveys (Voting sheets). At key points, the lessons call for the students to vote on their belief about the target problem and other bridging examples. While some teachers may choose to skip some of the indicated votes, we have found that they give the teacher valuable information on the students' conceptions and how they change during the lesson. Along with the vote, the suggested voting sheet, Figure 1, asks students to report "how much sense" each answer makes to them. This is a way to distinguish between what students "know from having been told" and what they "know because they really believe it". The "makes sense scale" on the voting sheets has been found to generate an open attitude later in the course. The simple use of these voting sheets conveys to the student the notion that their teacher really cares not only about the right answer, but the extent to which that answer makes sense to them. Students should be given the instructions that accompany the voting sheet (Figure 2), in order for them to understand what is meant by the "makes sense score".

OPINION SURVEY

Period ________ Date ________
Name_____________________

Vote	1 Makes no sense to me	2 Makes only a little sense to me	3 Makes some sense to me	4 Makes quite a bit of sense to me	5 Makes perfect sense to me
Vote 1	1 Comments	2	3	4	5
Vote 2	1 Comments	2	3	4	5
Vote 3	1 Comments	2	3	4	5
Vote 4	1 Comments	2	3	4	5
Vote 5	1 Comments	2	3	4	5

Figure 1

WHAT MAKES SENSE?

Instructions for Make Sense Scales on Voting Sheets

Please rate your answer on the voting sheet for how much sense it makes.

(Read five choices on the voting sheets.)

Throughout our lives, we have had a wealth of experience with the physical world which leads us to feel that some things make sense and others do not. A statement makes sense when we understand it at an intuitive or a "gut" level.

At times, we are confident about an answer, and it makes perfect sense. For example if a large truck runs into a small car, most people are confident that the car will get damaged. It also makes sense to them that the car would be damaged.

However, there are times when we know an answer is correct, (that is, we are very confident in our answer), but it does not really make sense. For example, many people are confident that when a person throws a boomerang, it will come back. But it does not make sense to them that it should come back. What makes sense to them is that the boomerang should just go in a straight line. How would you mark the makes-sense scale in this case, for the answer that the boomerang can return to the thrower? (You would be expected to answer 1 or 2.)

The scale asks you to rate how much sense each statement makes, not how confident you are about the truth of the statement.

Please circle a number beside each vote indicating how much sense your answer makes to you.

The comment space is available should you feel the urge to write a comment on any of your votes. Your teacher may specifically request comments on some votes.

You will not be graded on your answers or "Make Sense" ratings on these sheets, but you are expected to answer each question.

This will help you take a more active role in the learning process and give the teacher valuable feedback on the lesson.

Figure 2

Discussion. These lessons will be most effective if you encourage open discussion. Students should think about and explain what they believe about a physical situation, not just cite an authority. You should appear neutral until all points of view have been heard. This is not always easy to do and may take some practice. If there is not enough diversity of views, you may want to play devil's advocate for a while to encourage discussion. All this takes time, but we have found that the discussions promote students' conceptual understanding. Furthermore you will learn a great deal about your students' conceptions for future reference in your own lesson designing--both preconceptions that pose difficulties and potentially useful anchoring intuitions.

Large group voting. The ordinary way for students to vote on an issue is the private vote using the individual voting sheets. Teachers may also wish to ask for a public vote by a show of hands in addition to marking the sheets. The advantage of this procedure is that it gives the teacher immediate feedback on the students' ideas. However, the information is incomplete, since a strong majority of the students can sometimes vote together but with very low makes sense scores. The uncertainty present when many students have low makes sense scores is not indicated in a public vote. An alternative is for the teacher to walk quickly up and down the aisles to get a visual sense of how students are voting.

Voting in pairs. Another variation is for the students to vote in pairs. Students sitting next to each other are asked to discuss the vote issue for a minute or two (announcing a time limit is sometimes helpful) and then enter their individual votes on their own sheets. This has the great advantage of increasing student thinking and involvement, but takes slightly longer. It also may help students who are shy to participate more in the large group discussions, since they will have had some practice articulating their beliefs to their partner. Pair voting is especially helpful early in the year with groups that need encouragement to participate in open discussion. Since voting sheets are not graded, except possibly for effort, there is no problem of partners "copying".

Dynamics. Classroom dynamics will vary and occasionally a class has the opposite problem of being too argumentative so as to make some students reluctant to speak. A helpful procedure for setting a non-threatening tone if a discussion feels a bit too aggressive in tone is the following. During a public vote, the teacher records the number of students voting for each answer on the board. He or she then asks for comments in support of the different views represented on the board. Next, comments are solicited arguing against the different views. This serves to focus criticism on a view represented on the board instead of on a particular student and can serve to distance an individual student from direct criticism.

It is recommended that the teacher try different voting styles in order to introduce some variety into the classes. The introduction to the "makes sense scores" in Figure 2 should, however, be presented by the teacher with care to insure that the class understands this concept.

The Nature of Student Preconceptions and Misconceptions

Various terms such as 'preconception' and 'misconception' have been used by educators to describe critical barriers to learning. It is important to explain what we mean by a term like 'misconception' in this context, since we do not want to imply that students' ideas are largely dysfunctional. By 'misconception' we mean an idea that is in disagreement with currently accepted physical theory in the context being discussed. A preconception is a knowledge structure or disposition that a student has prior to a given course. We do not want to suggest that all misconceptions need to be "stamped out". But in order to understand Newtonian mechanics, students must become aware of contexts where intuitive misconceptions conflict with Newtonian models.

For example, students who hold the "motion implies a force" preconception believe that it requires a constant force to keep an object moving at a constant speed. In contrast, the physicist believes that an object moving at a constant speed has a zero net force acting on it. Students presumably derive their belief from examples like the forward force they need to apply to keep a wheelbarrow moving at a constant speed on level ground. They tend not to recognize friction as an equal opposing force in this situation. Their system of beliefs here is a successful and adaptive one in everyday life and is consistent with the way they move things around in the world from their point of view. So it would be unfair in this case if, by calling 'motion implies a force' a misconception, we meant that it is good for nothing and never works. Rather, we mean an idea that can generate a conflict when learning about the scientist's more general system of conceptions. Thus, some prefer to use the term 'alternative conception' rather than 'misconception' to avoid any negative connotations. It is likely that even physicists retain some misconceptions such as the "motion implies a force" idea and use them at an automatic level in everyday situations like pushing a wheelbarrow when there is no need to apply their more sophisticated physics knowledge. Thus we do not aim in these lessons for a complete elimination of all misconceptions. Rather we hope to make students aware that ideas like "motion implies a force" are in conflict with accepted physical theory when the physicist's point of view is required. In order to help avoid inappropriate negative connotations we will use the phrase 'preconception that poses difficulties' or 'conflicting preconception' when appropriate instead of 'misconception' throughout most of this book.

Other preconceptions are intuitions that are in basic agreement with the physicist's views. Here we will call these 'anchoring intuitions' and attempt to build on them. Finally, on some occasions we will find that a student's naive idea is somewhere in between a misconception and an anchoring intuition--partly right and partly wrong in the physicist's view. In this case we can attempt to modify the idea to be more like the physicist's.

In summary, a misconception or 'conflicting preconception' is an idea that is in disagreement with currently accepted scientific knowledge in particular contexts. Many brilliant ideas put forward in the history of science are now also misconceptions by this definition. Some of the student's misconceptions are adapted to everyday situations, and should be respected as creative constructions of the individual. Under no circumstances should they be criticized as foolish. However, many of them are persistent and we do need to make students aware of the contexts where they are in conflict with the theories of physics.

Suggested Possible Sequences of Units

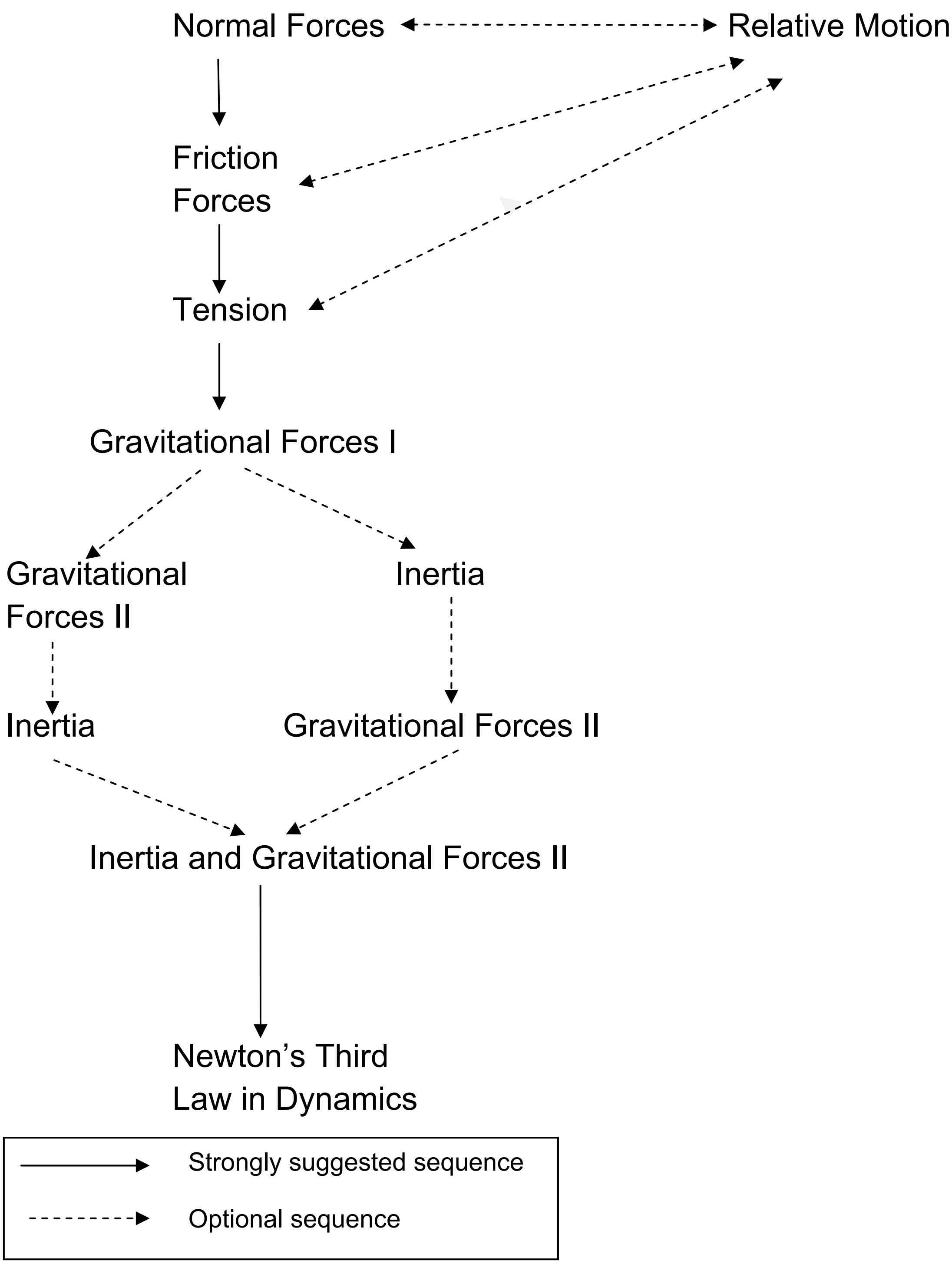

Figure 3

Useful Equipment

I. Normal Forces From Static Objects
Mattress Springs
One Truck coil spring if available
Laser or other source for light beam
Identical Magnets of Equal Mass and Unequal Strength (For optional section)
Two Springs for Spring Lab each with different spring constant per group in lab
One Compression Spring Device per lab group (for optional section)

II. Relative Motion
Battery-powered Toy Vehicle (constant **low** speed) one per lab group or at least
One for demonstrations
Large Sheets of Newsprint Paper or a sheets of thin plywood

III. Surface Frictional Forces
Pair of Wire Brushes
Spring Scales 20 N (transport type that shows the spring)
One or two dynamics carts with a flat surface attached to the top

IV. Tension Forces
Spring Scales 20 N (transparent type that shows the spring inside)
  a. Assorted rope, “S” hooks, bungee cord, and pulleys

V. Gravitational Forces I
Vacuum Pump
Bell Jar (large enough to contain a spring scale supporting a small mass)
One globe and some clay

VI. Gravitational Forces II
Long Rubber Bands, Wooden Blocks, and Nails

VII. Inertia
Skateboard(s) or one hover craft (one for a demo or more for the lab option)
One or two dynamics carts with open flat top surface and a smooth ball (perhaps lacrosse)
Stop watches (one per lab group)
Spring Scales (20 N) one per lab group
Inertial Balance
Dynamics Carts (two per lab group of 4 students)

VIII. Inertia and Gravitational Forces
Volleyball or Basketball full of sand and one regular one
NASA Videos
Vacuum Pump and Tube containing penny and feather
Dynamics Carts, Bricks, and 100gr Masses for demo or Lab

IX. Newton's Third Law in Dynamics
Two Dynamic Carts (one pair per lab group) with Spring Plunger
One Bed Spring
One Auto Spring if available
Two Low Projector Carts or Computer Chairs with smooth wheels
Two identical Bathroom Scales (Not Digital)

UNIT 1

Normal Forces

UNIT #1 - NORMAL FORCES

I. OVERVIEW OF THE NORMAL FORCES UNIT

A. MAJOR PRECONCEPTIONS POSING DIFFICULTIES IN THIS UNIT

1.) Solid objects do not exert forces.

2.) When two stationary objects push on each other, the "stronger" one exerts a larger force.

3.) When two bodies interact, the "stronger" body pushes with a greater force than the weaker body.

4.) When two bodies push on each other, the harder one pushes with a greater force than the softer one.

B. GENERAL STRATEGY OF THIS UNIT

This unit contains two lessons and one laboratory activity with springs, designed to introduce students to some fundamental considerations about the nature of force. The introduction in the previous chapter gave an overview of the instructional strategies to be used in this unit. The laboratory activity stands alone quite well and could be done early in the year before or after the two lessons in the unit. We strongly recommend using the lab before teaching any other units about force in this document, as analogies to springs are used extensively in later units.

The two lessons contain a series of bridging situations analogous to the target problems and to the anchors (see Figure 1.1 and the concept diagram in Figure 1.2). The foam pad and flexible board cases are examples which have some features in common with the target problem and some with the anchor - but also have some features that are qualitatively different. For example, the foam pad deforms perceptibly whereas the table does not. The basic strategy of this unit is to use these intermediate examples to bridge the conceptual gap between target and anchor, and to help students transfer the correct intuition about an upward force in the anchor situation to the target problem.

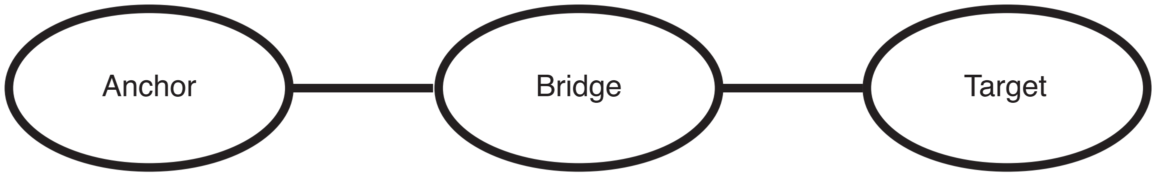

Figure 1.1

You are urged to draw the concept diagrams on the board as the lessons proceed so these examples will be available for easy reference, and to encourage students to make comparisons between situations. Draw the bridging situations between the target and anchor situations as shown on the concept diagram.[1]

In accordance with our general strategy of appealing to mechanisms and causal agents and not just to rules, the lessons then introduce a microscopic model - one that is visualizable - consisting of an imaginary network of spring-like bonds between molecules that pushes back when it is deformed. We do not introduce the molecular model for its own sake, but to provide an alternative to the concept of a perfectly rigid body. (Rigid bodies *do* have some use in physics, but in this context they get in the way of learning.)

C. THE PHYSICIST'S VIEW

A number of interesting questions and examples are raised by students in the discussions during this unit. The teacher may wish to anticipate some of the difficulties below.

- Students have occasionally raised the question of an "ideal table" which would not bend at all. Here we recommend allowing discussion if there is a lot of interest in this issue. If students press for teacher response in this area, it would seem reasonable to respond that physicists believe that tables, even the most solid ones, are made of atoms with spaces in between them. Therefore, whatever conclusion we come to about the ideal, perfectly rigid table would be difficult to apply to the real world.

- Others ask: "How does the table know how to push on an object?", "Is it intelligent?" This is another important discussion question. It may be fruitful to direct the discussion back to the spring at this point. The physicist's view is that the larger weight deforms the table more so that the table provides a greater normal force.

[1] Discussion in a given class may cause you to change the bridging sequence at times.

- A harder question is: "If a feather is sitting next to a football player on the table, how does the table know how hard to push on each?" Here one needs to refer to both compression and bending of the imaginary "network of springs" in the table, the compression under the football player being larger.

While the term "normal forces" is used as a title for this unit, these words have not been used within the lessons. Should the teacher choose to introduce the term at this stage it is important to clarify the meaning of the word "normal" in this context. Many high school math curricula do *not* use the word "normal" to mean perpendicular so some students may interpret "normal" as meaning something like "ordinary." In any case the "normal force" idea will be introduced in the Unit #3 which includes friction forces.

Some students may view the car pushing on the hydrant problem in Day #2 as different from the book on the table problem in Day #1 because (a) the force of gravity is more predominant in the table problem, and is an "action at a distance," and (b) the touching surfaces are vertical in one case and horizontal in the other. To physicists and teachers of physics, the similarity of the two situations may seem obvious, but to students struggling with these new ideas they may seem quite different.

An objective of this unit is to help students understand that the magnitude of forces between objects depends on the distance between the centers of the objects. An appeal to the molecular model introduced in Day #1 should help make this point clear to students. A stiff and a soft object can exert equal forces if the soft object is compressed more. Understanding this point will also set the stage for later work in a number of lessons.

II. NORMAL FORCES – LESSON 1

A. OVERVIEW OF THE LESSON

The *target* problem for this lesson is the "book on the table" problem shown in the concept diagram. The key question we are asking is: "Does the table exert a force on the book?"

We recommend that you avoid the question of the equality of the opposing forces in this lesson, but concentrate on the *existence* of the upward force. Once that is well established, you can tackle the equality issue in Day #2.

The *anchor* in this lesson refers to the "hand on the spring" situation shown in the concept diagram. Here we ask the question: "Does the spring exert an upward force on your hand?" We have found in diagnostic tests that the great majority of high school students (even before they have taken any physics) have a correct intuition about this question.

B. MATERIALS

1.) a book or a large feather

2.) a large spring (mattress spring is a good choice)

3.) a block of soft foam

4.) a pair of meter sticks to use to simulate a flexible table (or perhaps thin balsa wood sticks if you are using a feather instead of a book)

5.) a laser and a small mirror (an alternative light source with a narrow pencil beam will work)

6.) voting sheets (with introduction on the back)

7.) Homework sheets - Normal Forces - Day #1

8.) Concept Diagram sheets - Normal Forces - Day #1 (attached to homework)

C. OBJECTIVES

1.) The lesson should help the student construct the conceptual model that solid objects are elastic and that they exert a force when a force is exerted on them.

2.) The lesson should help the student construct the microscopic model that solids are elastic because of spring-like bonds between their molecules.

D. CONCEPT DIAGRAM - NORMAL FORCES - DAY #1

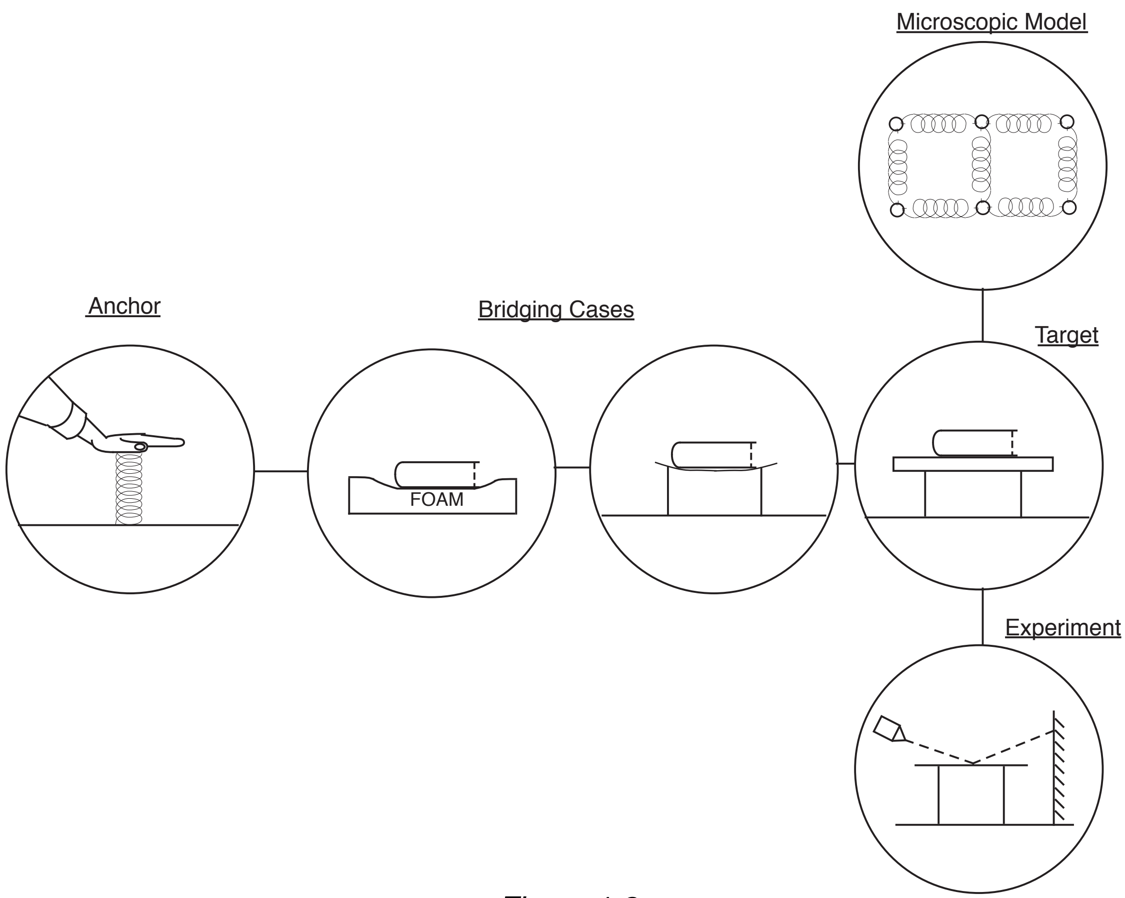

Figure 1.2

E. **LESSON PLAN - NORMAL FORCES - DAY #1**

1.) Introduce voting sheets

a.) Pass out voting sheets with the sheet that explains their use. If this is your first use of the sheets have students read the introduction about the boomerang and then answer any questions. Emphasize the fact that these questions do not count on their grade, but that they are important.

2.) Introductory remarks about force

a.) We are beginning to investigate the nature of the concept called "*force*."

b.) Suggest the following definition (on the board): "*A FORCE IS A PUSH OR A PULL OF ONE OBJECT ON ANOTHER OBJECT.*"[2]

c.) Notice this definition is only a starting place and will be refined and expanded during this course. Consider the fact that this definition does not tell you what a force *is not* so we will be spending time clarifying and building on this notion as used by physicists. For example, we will not include social forces or economic forces.

3.) Book on the table - target problem

a.) Draw the diagram.

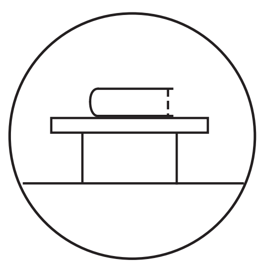

Figure 1.3

[2] See Teaching Note #2 at the end of the lesson.

b.) <u>Vote #1 - Question</u>

"Does the table exert an upward force on the *book*?"[3]
or "Does the table push up on the book?"

c.) Choices:

- Yes
- No

d.) Please circle the makes sense score on your voting sheet and write in a comment if you wish.

4.) <u>Discussion of the target problem</u>

The discussion can extend 15-20 minutes and should be as lively as possible with a variety of inputs from students. Students may introduce some of the ideas below on their own. The teacher is urged to remain neutral during this discussion.

5.) <u>Demonstration and discussion - introduce the anchor</u>

a.) Demonstrate pushing down on a spring (like a bed spring)

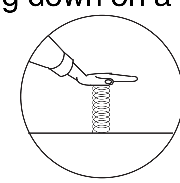

Figure 1.4

b.) <u>Vote #2 - Question</u>

"Does the spring exert an upward force on the hand?"

Choices:

- YES
- NO

Remember the makes sense score.

c.) *Discussion Questions*:

- "How is this situation like the book on the table?"
- "How are the situations different?"
- "Could someone who felt the table and the spring are different please tell us why?"

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[3] A "feather" may be more appropriate than a book for higher ability or more advanced level classes. However, the book will be used throughout this lesson.

6.) Book on a soft foam pad (bridging example)

a.) Introduce the idea of the book on a *soft foam pad*.

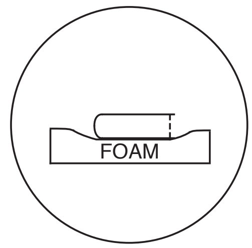

Figure 1.5

b.) Vote #3 Question:

- Does the foam exert an upward force on the book?

c.) Discussion Question

- Is this case the same or different from the table case? Why?

7.) Book on a flexible board (bridging example)

a.) After discussion of the foam, introduce the idea of the book on a *flexible board* (demonstrate with meter sticks as table top). Balsa wood sticks may be needed to show a deflection with a feather.

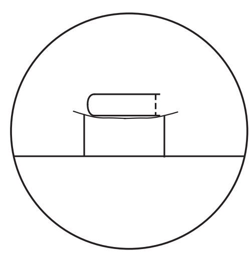

Figure 1.6

b.) Vote #4 Question

Does the flexible board exert an upward force on the book?

c.) Discussion questions

- Is this case the same or different from the table case? Why?
- Does the situation change as you think about the board gradually becoming thicker? Why?
- At what thickness does it become rigid?

8.) Later discussion[4]

As the discussion/conflict evolves, the following questions *might be* used to *challenge* those people who seem to believe the table pushes up.

a.) *Challenge:* Where does the force of the table come from?

9.) Vote #5 – Target Problem again

Repeat *Vote #1*: "Does the table exert an upward force on the book?" Comment that you are really interested in the makes sense score.

10.) Springy atomic model for solids

a.) Introduce a springy atomic model for solids (draw Figure 1.7).

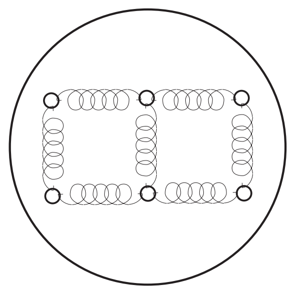

Figure 1.7

b.) Consider the solid table to be made of atoms connected by bonds that are somewhat like springs.

c.) Ask the class how this view of a very solid table could explain the mechanism with which the table can exert an upward force? (Refer to anchor picture if necessary).

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4 If time is available

11.) Demonstration (teacher stands on the table)

Laser beam reflecting from a small mirror near the center of the lecture table deflects when the teacher steps near the mirror.[5]

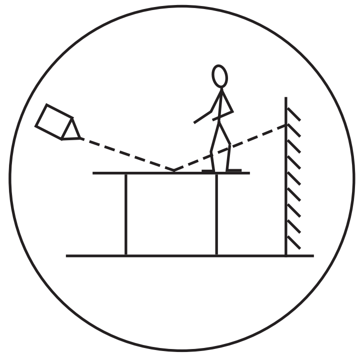

Figure 1.8

12.) Vote #6 - Final vote on the target problem -

Repeat Vote #1: "*Does the table exert an upward force on the book?*" (again).

13.) Defining the Normal Force

If the teacher is satisfied that most students have grasped the concept, then the upward perpendicular force of the table on the book can be identified as a Normal Force. See the Physicists' View preceeding this lesson.

14.) Summary question

Which of the diagrams on the board most helped you imagine that the table exerts an upward force on the book?[6]

15.) Homework

Pass out the homework for Day #1 with the attached Concept Diagram, Normal Forces Day #1.

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[5] This demonstration is very helpful for some students.
[6] Could have them record this response as Vote #5 or have a show of hands.

F. TEACHING NOTES - NORMAL FORCE UNIT - DAY #1

1.) It is suggested that this lesson is most exciting and effective if the teacher withholds his/her position as long as possible (until the atomic model). Students are almost certain to have strong feelings on both sides of the struggle and these should be drawn out to make the class more exciting. Should some students complain that they really need to know the correct answer, just assure them that you plan to make your opinion very clear in the near future. If only one side seems to be represented a bit of "devil's advocacy" may be a useful strategy.

2.) Should students complain that they don't know what you really mean by "force" assure them that they are asking an important question and the struggles in this lesson will help them become clearer about what physicists mean by "force".

3.) The definition of force given in this lesson (a push or a pull) suggests muscular force, and more generally contact forces. Some physicists may object that this is too limited a definition. But the most rigorous definition is not always the most useful for a beginner. We want to start by building on the learner's intuitive ideas. There will be time for the concept of force to be refined and generalized. It would be useful to point out to students that this definition is an initial one, to be elaborated as their physics understanding grows.

4.) If the *equality* of the forces arises during discussion on the first day, avoid it by saying you want to concentrate on whether the force *exists* and how to explain it.

5.) Introducing the molecular model as a mental image also makes it available later for the study of collisions, friction and tension. It is important to point out that this is *only* a model, and that all models have limitations.

6.) The demonstration (see Figure 1.8) with the teacher standing on the table is fun and very helpful to some students. The teacher should practice this a bit, but the general setup in Figure 1.8 worked well for our classes. The downward deflection of the light will be greater if the mirror is placed between the side and the center of the table closer to the light source. Even a small deflection of the spot on the wall seems to impress students.

7.) When the term “normal” is introduced, the teacher should emphasize the fact that this means perpendicular to the surface whether the surface is horizontal, vertical, or inclined. This should also be emphasized during the discussion of the homework problems.

III. NORMAL FORCES – LESSON 2

A. OVERVIEW OF THE LESSON

Unlike the previous lesson, where we were mainly concerned with the existence of forces from static objects, the main objective of this lesson is to help students build the notion of *equality* of the forces exerted on one another by a pair of static objects in contact. Although these sources are also equal in accelerated situations, we deal with the static case here for simplicity and reserve the dynamic case for treatment in Unit 9. The *target problem* in this lesson is the "car pushing on the hydrant" problem (see concept map Figure 1.9): in which we ask students to compare the magnitudes of the force exerted by the car on the hydrant and the force exerted by the hydrant on the car. There is no motion. The *anchor situation* is a person pushing with the hand against a spring attached to a vertical wall with the same question of relative magnitude of the forces exerted by hand on spring and spring on hand.

An additional anchor (to be used if the first one doesn't seem to convince some students) is the case of a cart with opposing forces pushing on each side. The goal is to have students understand and apply the notion that the object will move (accelerate) if the forces acting on it are not balanced.

As in Lesson #1, the strategy is to determine initially that most students have the correct concept for the case of the anchor(s), and then to bridge the conceptual gap between target and anchor(s) by suggesting several intermediate examples (the intermediate diagrams in Figure 1.9). Students are asked to make comparisons between these intermediate examples and the target and anchor(s), so that the students are able to extend the correct intuition in the anchor case to the target problem.

The closing portion of the lesson allows for completion of some in-class experiments with rubber bands of unequal strengths. Another optional extension uses magnets of unequal strength.

B. MATERIALS

1.) pairs of connected, unequal rubber bands for the entire class

2.) a bed spring and an automobile spring

3.) pairs of magnets of equal mass but different strengths (optional section)

4.) voting sheets

5.) Homework sheets - Normal Forces - Day #2

C. OBJECTIVES

1.) The student should understand that when any two static objects interact (push or pull on each other), the forces are equal in magnitude and opposite in direction.

2.) The student should understand that the size of the force of interaction depends on the degree of deformation in the objects.

3.) The student should understand that when two static objects interact the forces are equal and opposite even if the two objects deform by very different amounts.

D. CONCEPT DIAGRAM - NORMAL FORCES - DAY #2

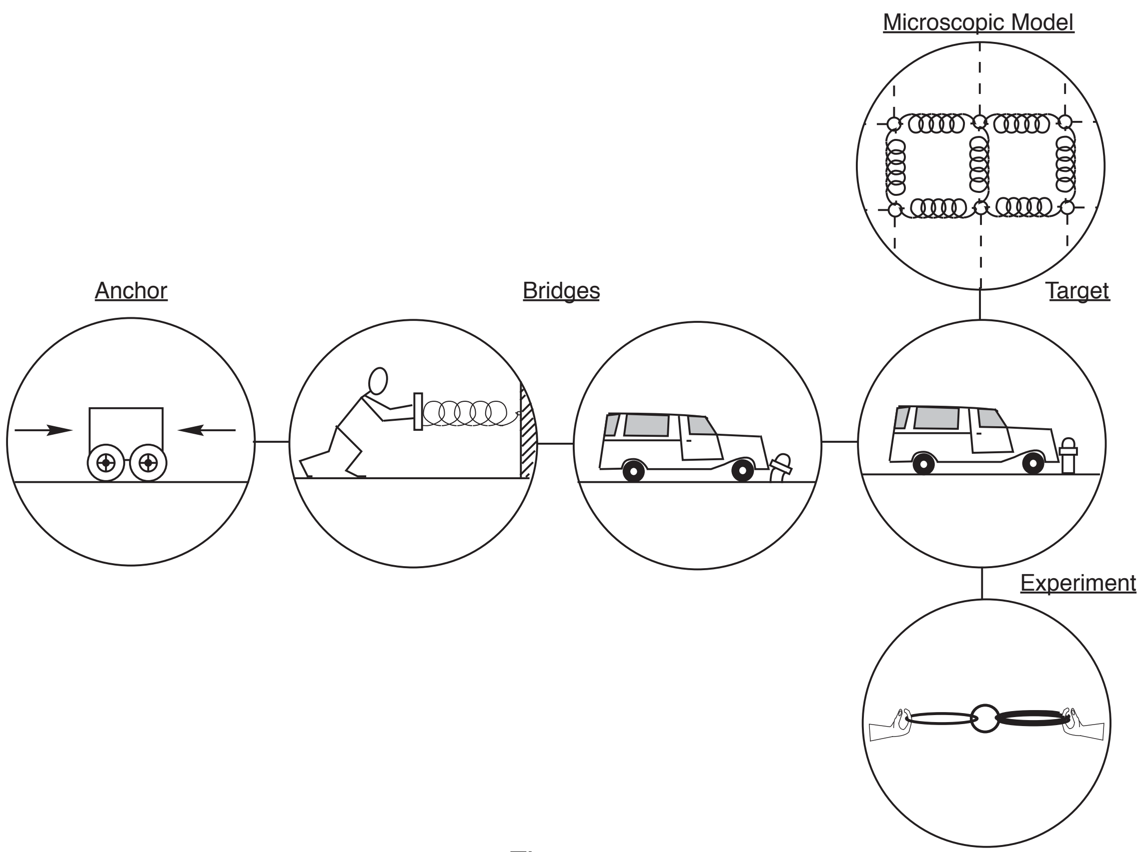

Figure 1.9

E. LESSON PLAN - NORMAL FORCES - DAY #2

1.) Voting sheets

Pass out voting sheets (perhaps a brief reminder here about the meaning of the makes sense score).

2.) Homework discussion

Discuss any matters of concern that the students have related to the homework problems from Day #1.

3.) Generalization presented

Try to establish the generalization below after reviewing the homework items.

- "Matter is compressible ("squishy") and touching objects (even passive ones) push on each other."

4.) Introduce the target problem

a.) Draw the target problem of the car pushing on the hydrant.

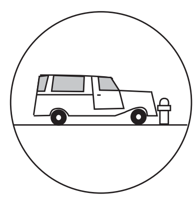

Figure 1.10

b.) Explain that the car slowly touches the hydrant and then pushes hard. Carefully explain the 3 choices below before the students vote. Point out the fact that the car is pushing hard but, there is no motion at the time we are comparing the forces.

c.) *Vote #1 Choices*

- $F_{c\,on\,h} > F_{h\,on\,c}$
- $F_{c\,on\,h} < F_{h\,on\,c}$
- $F_{c\,on\,h} = F_{h\,on\,c}$

5.) Discussion of Vote #1

a.) Share responses to the fire hydrant question.

b.) Encourage input from students with differing views.

6.) <u>Present the anchor problem (pushing a spring)</u>

a.) Draw the picture of the anchor situation.

b.) Demonstrate pushing on a board on a spring.

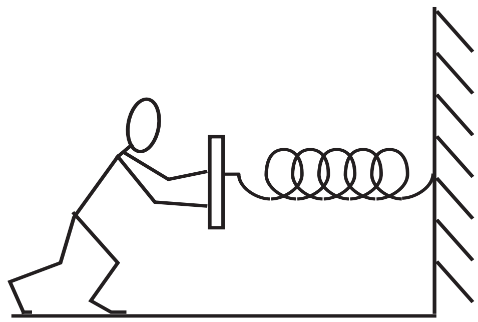

Figure 1.11

c.) Think of the forces *acting on the thin board* between the hand and the bed spring. Compare the force of the hand on the board to that of the spring on the board. (Demonstrate if possible with a bed spring and a thin board.)

d.) Discussion question:

What would happen to the board if one force were larger?

7.) <u>Vote on a bridging example - Hand on spring *without* board</u>

a.) Demonstrate the hand pushing on the spring *without a board*. Explain that we are considering the force of the hand on the spring and the force of the spring on the hand.

b.) <u>Vote #2 choices</u>

Explain the choices:

- $F_{h\ on\ s} > F_{s\ on\ h}$
- $F_{h\ on\ s} < F_{s\ on\ h}$
- $F_{h\ on\ s} = F_{s\ on\ h}$

c.) Discuss responses to Vote #2.

d.) *Challenge* people voting for equality with the question:

How does the spring "know" how hard to push back?

8.) Introduce the automatic force equalizer

a.) Introduce the idea of a spring as "*an automatic adjustable force equalizer .*"

b.) Demonstrate pushing a stiff spring and a soft spring into each other. A bed spring and a truck spring will get the student's attention.

c.) Ask students to explain how the springs both adjust to exert equal and opposite forces.

9.) Consider this optional example if some students are still having conceptual difficulties.

a.) Question:

What happens to a cart if you push on two sides with different forces?

b.) Draw Figure 1.12.

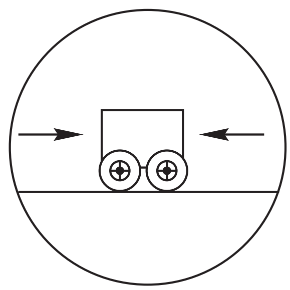

Figure 1.12

10.) Introduce the bridging examples

a.) Consider a car pushing on a very strong rubber hydrant.

b.) Draw Figure 1.13.

c.) Vote #3 Choices

- $F_{c\ on\ h} > F_{h\ on\ c}$
- $F_{c\ on\ h} < F_{h\ on\ c}$
- $F_{c\ on\ h} = F_{h\ on\ c}$

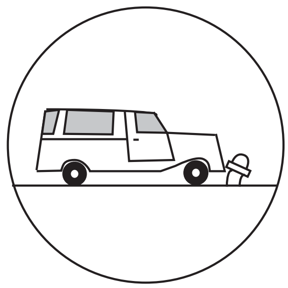

Figure 1.13

d.) Discussion Questions

- How does this compare to the original problem?
- If the car is stiffer than the hydrant, should it exert more force?

11.) Another bridging example to offer (optional)

a.) Consider a person pushing on a wall.

Ask, "How does the wall ‘know’ how hard to push back?"

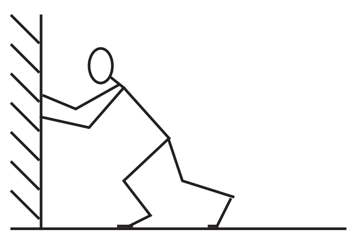

Figure 1.14

b.) Offer the comparison with the hand pushing on the spring.

c.) Review the *"automatic adjustable force equalizer"* concept.

12.) Introduce an experiment to verify the "*automatic adjustable force equalizer*" concept [7]

a.) Demonstrate the rubber band apparatus. (*No motion* is allowed for testing the rubber bands). Explain that one student will close his/her eyes and the other student will attach the stretched apparatus to the outstretched fingers of the first.

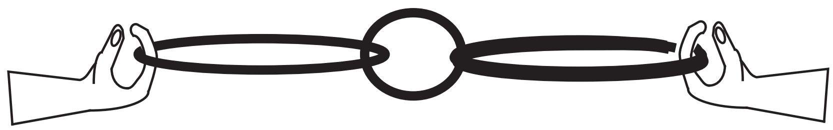

Figure 1.15

b.) Vote #4 (precedes the experiment)

Which of my hands will feel the greater force, the strong band or the weak band?

c.) Choices:

- strong > weak
- strong < weak
- strong = weak

13.) Class experiment activity (rubber bands)

a.) Pass out one rubber band set up to each pair of students. Have them test the *static case* with a partner's eyes closed.

b.) Take turns and continue until most students get the same result (only a few minutes).

c.) Collect the equipment.

d.) Question: *How is it possible for the "strong" band and the "weak" band to produce equal forces? How does each work?*

[7] If the class has not already done the lab activity with springs under both tension and compression, the teacher may need to help here with the idea that springs (and bands) automatically adjust their lengths to exert equal and opposite forces when they are stretched.

14.) Generalization

a.) Ask for a generalization about how stretching things work when connected.

b.) Consider the situation below if another concrete example is needed.

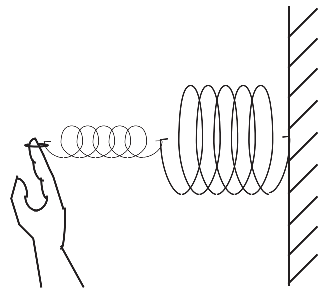

Figure 1.16

c.) Thought experiment question about Figure 1.16.

Which is larger? The force of the *hand on the stiff spring* or the force of the *wall on the soft spring*?

d.) Point out that springs work the same way for compression.

15.) Formal presentation of a generalization[8]

Try to draw out a generalization of the static third law. List the previous situations covered. We've been looking at a number of situations. What do these situations have in common? Can someone give a general statement concerning the forces between objects that interact with each other?

"$F_{A \text{ on } B} = - F_{B \text{ on } A}$" (explain notation as needed).

16.) Vote #5 - The target problem again

a.) Repeat Vote #1 - The car pushing the metal hydrant

17.) Homework

Assign Homework - Normal Forces - Day #2.

8 Should you choose to include the optional section 18 about "force at a distance" with magnets you probably should save this section until the end of the lesson.

18.) <u>Force at a distance example (optional)</u>
Two magnets of unequal strength but similar size and weight are needed.

a.) Now we consider a force that works at a distance.

b.) *Demonstrate* to the class that one magnet is much stronger than the other. (One will pick up many paper clips).

c.) <u>*Vote #4*</u> (comparing strong and weak magnets)

Which hand will feel the greater force?

- S > W
- W > S
- S = W

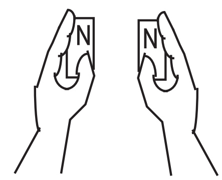

Figure 1.17

d.) *Experiment* (optional): Pass out pairs of magnets to groups of students. Have each student try to say which is stronger while keeping her/his eyes closed and moving the magnets near each other. Magnets should have similar size and weight.

-or-

Demonstrate with a volunteer student, if you have only one set of magnets.

e.) If time permits, introduce the baby magnet model. Students should be willing to accept the notion that one can identify a smallest *unit* of magnetism. Note equal number of lines each way leads us to expect equal forces (we assume baby magnets are equal in strength.)

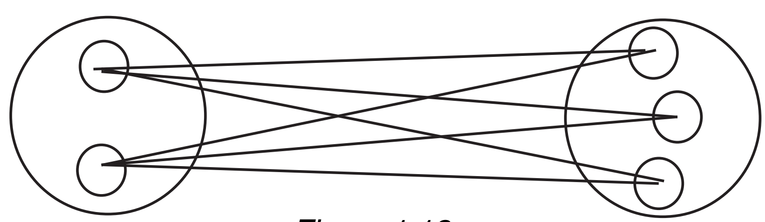

Figure 1.18

2 forces pull on 3 units

3 forces pull on 2 units

F. TEACHING NOTES - NORMAL FORCES - DAY #2

The first part of this lesson should be a *brief* review of the homework and summary of last class drawn into a generalization. Try not to get bogged down here, for there are many good ideas suggested in this lesson.

The major thrust of the lesson is concerned with the *equality* of the contact forces. Some students will find a line of argument that "forces must be equal because unequal forces would produce motion" to be rather unconvincing. Perhaps a careful discussion of the forces exerted by two rubber bands of different stiffness cemented together or two different springs pushing together will be more helpful for these students. The teacher's style can be quite flexible in the main body of the lesson encouraging students to introduce bridges or offering bridges from the lesson plan that seem the most helpful. We would, however, still urge the teacher to withhold his/her professional position on the answer until very near the end of the lesson.

The teacher should carefully *avoid* being drawn into a discussion of the interactions between bodies in the *dynamic* case. If students are interested, assure them that the case for interacting forces during *motion* will be carefully considered later in the course. Try to stay focused on the static case for the purposes of this lesson. It is clearly not the intent of these lessons to deal with the third law in the dynamic case. The third law in constant velocity and acceleration cases should follow the study of inertia. That issue is the main focus of Unit #9.

The notion of a spring as an *"automatic adjustable force equalizer"* seems to be a helpful way of getting students to confront one of our major objectives. It is probably easiest to see a spring under tension or compression adjust its length so that the force of the spring balances the force of the outside agent acting on the spring.

If students are expected to write answers to the homework questions with emphasis on the mechanisms involved, this assignment will probably be more helpful to them. They should be urged to think in terms of springs while remembering all matter is made of atoms with spring-like bonds.

The homework problems include some questions with *unequal* forces - partly to keep students worried that the correct answers about forces are not always "equal." In other words we want them to keep thinking and analyze each situation. Problem 9 in the homework is placed at the end intentionally as it raises issues that the teacher may wish to avoid at this time. It may be included if the optional section about magnets was included as part of class discussion.

IV. NORMAL FORCES - EXPERIMENT - INTRODUCTION TO SPRINGS

A. OVERVIEW OF THE LAB ACTIVITY (FOR THE TEACHER)

This experiment provides an important opportunity for students to handle springs and take measurements of spring elongation (or compression) and applied force. An extension of the simple spring experiment involves connecting two springs, of differing spring constant, in series to find the behavior of the combined spring system.

In order to extend student's reflection in this area the lab may be extended to examine rubber bands, which are non-linear in behavior. We also suggest the section on spring compression, although the apparatus needed for this part is more difficult to arrange.

The teacher may elect to have students measure force with a spring scale (force measurer) calibrated in newtons or use masses and tell students to assume 100 g masses weigh 1 Newton each. In any case students need to become familiar with the Newton as a unit of force.

This experiment calls for students to plot elongation vs. force (as in Y vs. X) rather than force vs. elongation as is normally done. At this stage in the physics course many students think of force as the cause of the elongation and thus we suggest force as the independent variable for this early lab. Some teachers may feel they would rather introduce the graph in the $F = - kx$ form to be used later in the course.

If the class has not been exposed to the term "elongation" it will be necessary to be sure there is a clear understanding about the difference between elongation and length.

B. EQUIPMENT

1.) ring stands (1 per group)

2.) rings (from which to suspend springs)

3.) 2 springs per group (different K values)

4.) spring scale (1 per group) (range depends on spring constant)

5.) string

6.) rubber bands (2 different per group)

7.) spring compression apparatus (if available)

V. <u>MATERIALS FOR DUPLICATION</u>

A. Laboratory Activities

1.) Introduction to Springs Laboratory Experiment

B. Homework

1.) Normal Forces - Day #1

2.) Normal Forces - Day #2

C. Quiz and Test Questions - Normal Forces

INTRODUCTION TO SPRINGS
LABORATORY EXPERIMENT

Name: ____________________

Period: _____Date: ___________

I. ELONGATION OF SPRINGS

1.) Apply different amounts of force to your spring (using the Newton scale or masses), and measure the resulting lengths. Record your data in a neat and properly labeled table data and include a column for elongation. The elongation of the spring is the change in length as compared to the original or natural length with no force applied.

2.) Plot the elongation (change in length) of the spring vs. the applied force in newtons. Collect data for the three cases below. Plot the 3 lines on one graph.

a.) weak spring

b.) strong spring

c.) combination of both springs (in series)

3.) Questions:

a.) Using your graph, compare the elongations of the weak spring, the strong spring and the combined springs when the same force is applied.

b.) If the springs in case a, b and c are each elongated by the same amount which spring would exert the greatest force on your hand? Which spring would exert the least force on your hand?

c.) Do your graphed points produce lines or curves? Do they go through the origin? Explain why or why not.

d.) If someone were to plot the length of the entire spring instead of the change in length of the spring (elongation) - how would this graph be different from graphs that were plotted correctly?

II. ELONGATION OF RUBBER BANDS

1.) Collect and neatly tabulate the same data for the rubber band cases.

a.) weak rubber band

b.) strong rubber band

c.) combination of both rubber bands (in series)

2.) Plot the elongations versus force for the rubber bands again including three cases on one graph.

3.) Questions:

a.) Do the rubber bands show the same pattern as the spring graphs? Explain.

b.) Would a strong rubber band be a fair substitute for the spring in your spring scale? Why or why not?*

III. **COMPRESSION OF A SPRING****

1.) Apply different amounts of force to your compression spring, and tabulate your data.

2.) Plot the *compression,* (i.e. change in length) of the spring in millimeters vs. the applied force in newtons producing compression.

3.) Questions:

a.) If the compression spring were the same as one of your elongation springs, how would you expect the slopes of the two graphs to compare?

b.) *Predict* and *sketch* what you might expect to find if you obtained and plotted the data in a *compression experiment* for a:

- weak spring
- strong spring
- combination of two springs

c.) What do you think there is in the internal structure of a spring (or rubber band) that allows it to behave in the manner you discovered in lab?

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*Note: These questions are somewhat more difficult and the teacher may wish to delete them in some physics classes.
**Section II or III may be deleted from this lab activity based on the availability of time and equipment.

HOMEWORK - NORMAL FORCES - DAY #1

Name: ______________________

Period: _____Date: ___________

1.) In our class discussion I noticed that people's gut feelings varied a lot about the object on the table problem. Please write a paragraph explaining what there is about the nature of a solid table that allows it to push up on an object.

2.) Given a ladder leaning against a very solid and thick brick wall:

a.) Would you imagine that the wall exerts a force on the ladder?

b.) Defend your answer as clearly as possible explaining how the wall responds to the ladder (include a sketch if possible).

3.) If you have a germ sitting on a strong and solid table, do you believe the table exerts an upward force on the germ? Defend your answer as clearly as possible.

4.)

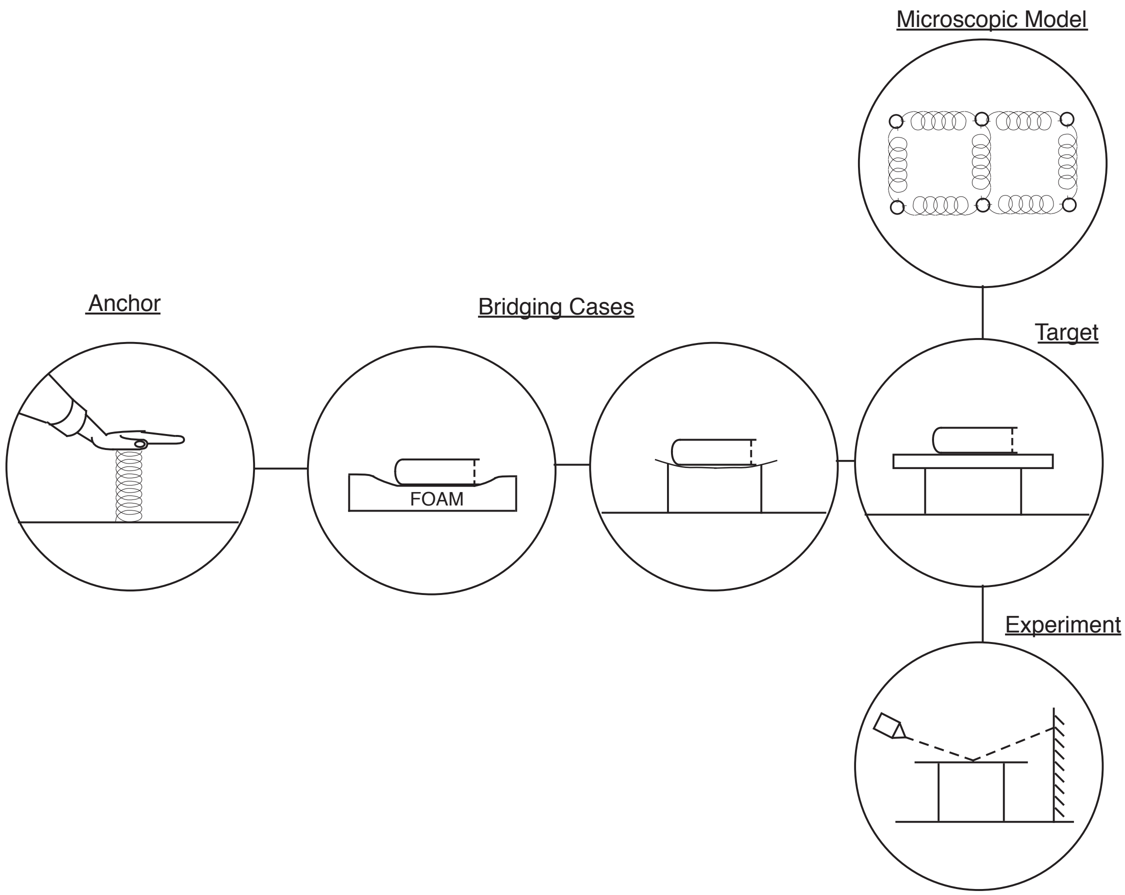

Figure 1. 19

a.) Which idea pictured in the concept diagram above is most helpful to you? Explain why.

b.) Which idea pictured above would you leave out of the lesson because it was not helpful to you?

5.) What is the "spring model" of solid matter and how is it useful in explaining forces between solid objects that are touching each other?

HOMEWORK - NORMAL FORCES - DAY #2

Name: ______________________

Period: _____Date: ___________

1.) Write a paragraph in which you explain how two springs of *different* stiffness could push with equal force on each other when pressed together.

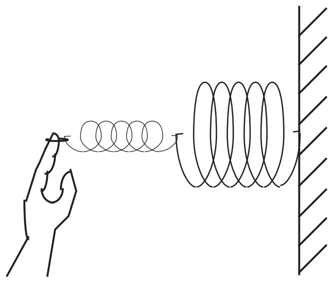

Figure 1.2 0

2.) How are rubber bands similar to springs and how are they different from springs? Be sure to consider tension and compression situations.

3.) Consider the forces shown in the figure below:

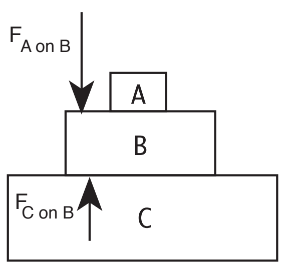

Figure 1.2 1

a.) How do the 2 forces compare? *Explain your answer carefully.*

b.) The force of C on B should be equal and opposite to some other normal force. Name that equal and opposite normal force.

4.)

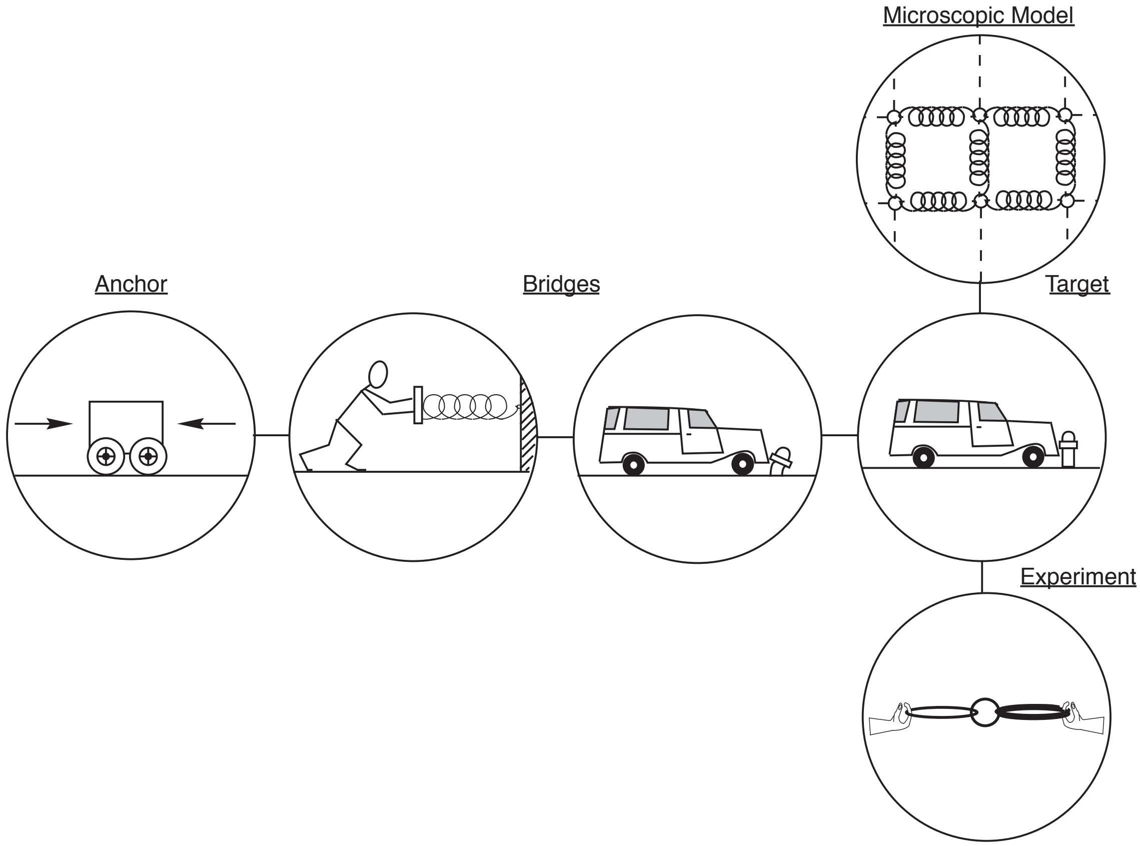

Figure 1.2 2

Which diagram above represents the idea that was most helpful to you? Explain how it helped.

5.) Consider the pile of cement blocks.

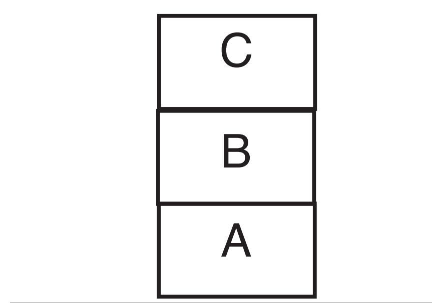

Figure 1.2 3

a.) How does the force of block B on block A compare to the force of block A on block B?

b.) How would these forces compare if block C were removed?

c.) Does block C exert a force on block A when it is added to the pile? Explain your answer.

d.) Do you imagine that block B changes shape when block C is added to the pile? Explain your answer.

6.) Describe three examples of two stationary objects pushing on each other in which it is hard for you to believe that the forces are equal and opposite.

a.)

b.)

c.)

7.) How would you convince a skeptical friend that a spring is an "automatic adjustable force equalizer"?

8.) Consider a pile of 3 bricks stacked neatly on a table. If you add a 4^{th} brick on top of the stack, explain what changes take place within each brick as the added weight of the 4^{th} brick is supported by the table.

9.) Write a paragraph in which you explain how it could be possible for a strong magnet and a weak magnet to push or pull on each other with equal forces.

QUIZ AND TEST QUESTIONS - NORMAL FORCES

1.) If I have a book on a table and I pick it up and replace it with a paper clip, how does the table 'know' how hard to push on the paper clip?

2.) Newton's third law states: "If any object A exerts a force on object B, then B exerts an equal and opposite force on A." How can you relate this law to the example of a book sitting on a table?

3.) If there is a mosquito sitting on one side of a table and a person sitting on the other side, explain how the table 'knows' how much to push up on each of these objects.

4.)

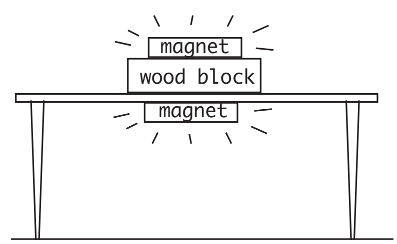

Figure 1.24

A block of wood is sitting on a table. A pair of strong but unequal magnets are positioned as shown. The magnets attract each other so that the lower and weaker magnet is held up against the underside of the table. How does the normal force of the block pushing down on the table compare with the normal force of the table pushing up on the block?

a.) table pushes harder

b.) block pushes harder

c.) depends on weight of the magnets

d.) forces are equal in size

5.)

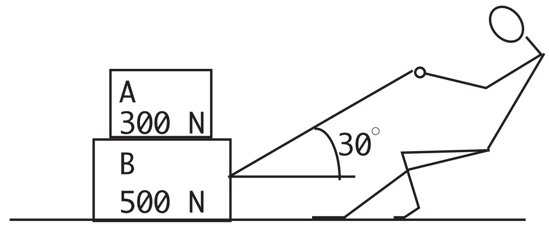

Figure 1.2 5

The weights of the boxes (in newtons) are indicated. Janet is pulling on the rope at a 30 degree upward angle, with a force of 400 N (vertical component 200 N, horizontal component 350 N). However the boxes do not move.

How strong is the force with which box B pushes on box A?

a.) 0 c.) 200 N

b.) 100 N d.) 300 N

e.) 500 N f.) 800 N

6.) The book in the picture below weighs 20 N. The book is held against the ceiling by a person who pushes up on the bottom of the book with a force of 25 N. Answer each of the following:

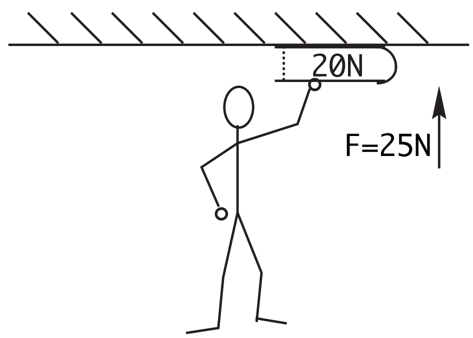

Figure 1.2 6

a.) The force of the book acting on the hand equals ___________

b.) The force of the book pushing on the ceiling equals ___________

c.) The force exerted on the book by the ceiling equals ___________

d.) What is it about the nature of the ceiling that allows it to exert the correct amount of force on the book? Explain.

UNIT 2

Relative Motion

UNIT #2 - RELATIVE MOTION

I. OVERVIEW OF THE RELATIVE MOTION UNIT

A. MAJOR PRECONCEPTIONS POSING DIFFICULTIES IN THIS UNIT

GENERAL

1.) Velocity is an intrinsic property of an object that does not depend on the observers frame of reference.

2.) The student has difficulty in viewing a situation from other than a single frame of reference, often the ground frame of reference. In particular, when an object moves on or in a supporting medium such as air or water, the motion of the medium does not affect the velocity with respect to the ground in an additive manner. The concept of two opposing velocities canceling each other is particularly counter-intuitive.

3.) Correct concepts about frames of reference moving on solid surfaces may not transfer easily to frames in fluid motion, such as air or water. Students may attempt to imagine a motion as seen from another frame of reference, but then "slip" back into the original frame of reference.

TWO DIMENSIONAL CASE

4.) Students may have difficulty visualizing a scene involving the addition of two velocities in two dimensions.

5.) In performing computations with vectors, students may lose track of the connection between a vector and the velocity (physical feature) it represents.

B. GENERAL STRATEGY OF THIS UNIT

The general goal in these lessons is for students to understand, on an intuitive level, motion relative to a reference frame that is itself moving with respect to the earth, and to be able to solve relative motion problems.

This unit consists of three lessons on relative motion involving (1) a jogger running on a train; (2) river-boat problems; and (3) airplane and wind problems. A laboratory activity is also provided which would probably be used between Lesson 2 and Lesson 3.

Although they are virtually the same problems to the physicist, students find the river problems to be significantly harder than the train problems, and the airplane problems to be harder than the river problems. Thus, the overall strategy is to develop an anchoring concept in the railroad car case in Lesson 1, and then to extend the concept to boats and airplanes in Lessons 2 and 3.

For students who are conversant with vectors, all the situations in these lessons can be represented as simple problems in using vector addition. Some high achieving students learn to recognize surface features of problem statements and correctly do the problems by a remembered algorithm. Students who want to *understand* rather than "get by" have a more difficult time overcoming a common intuition that: a person who swims at a speed of two miles/hour will be seen as moving at two miles/hour by all observers.

Within each lesson, the examples progress from simpler to more difficult according to another attribute: from one-dimensional problems (in which the motion of A relative to B is parallel or directly opposed to the motion of B relative to the Earth (Figure 2.1)), to two-dimensional problems (in which the above restriction is lifted (Figure 2.2)). The case of cancellation of two velocities seems especially important for students to work through.

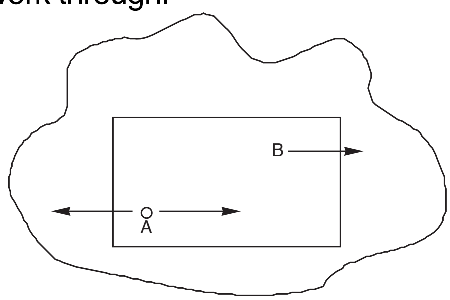

Figure 2.1

As in our other lessons, these lessons place great emphasis on thought experiments (physical situations not observed or measured, but imagined and thought about), augmented by class demonstrations and experiments. Also, these lessons call for periodic "votes", in which students are asked to answer, on paper, questions relating to thought experiments. We have found that making a commitment in writing leads the students to think hard about the questions, and that this forms a good basis for class discussions of the physics involved.

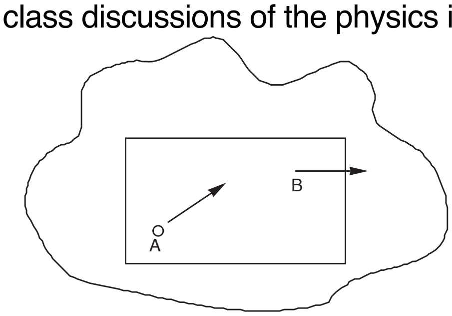

Figure 2.2

C. CONCEPT DIAGRAM - RELATIVE MOTION UNIT

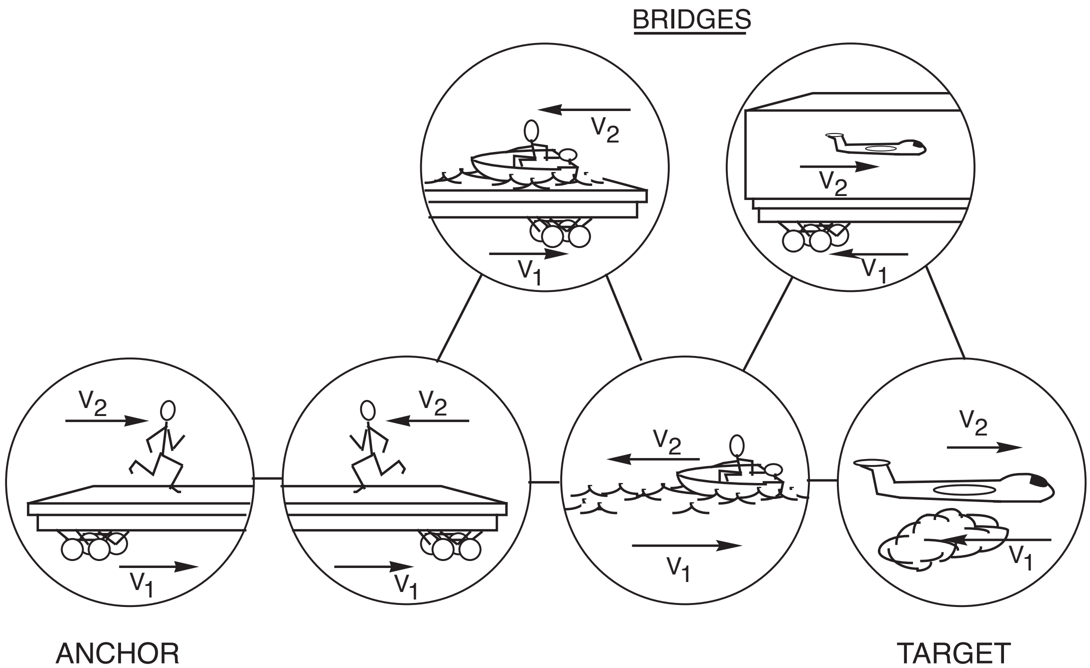

Figure 2.3

D. <u>THE PHYSICIST'S VIEW</u>

These lessons do not attack the general problem of relativity of all motion in the Galilean sense - let alone in the Relativistic sense. However, students have a strong intuition about the existence of an absolute, fixed system: the local, flat, surface of the Earth. These lessons make use of this intuition, and attack the problem of relative motion within this rather comfortable framework. Questions about the Earth itself being a moving - indeed accelerating - body, and its surface not being flat, are not considered in this unit.

Students have a great deal of trouble believing that water supports a boat in a way that is analogous to the way that the railroad flat car supports a person. Careful discussion to help them realize this and to be clear about what we mean by velocity "relative to the water" should prove very helpful. When students start to ask detailed questions about velocity patterns, it is important to make it clear that we assume steady currents as we cross a river. When students have trouble with wind, they are frequently thinking about wind gusts and must be reminded that we should assume steady state wind conditions when considering airplane problems.

The physical situations in thought experiments often have a bit of the absurd about them. Whoever heard of a boat in a swimming pool on a train or a plane inside a moving box car with glass walls? Why would anybody *care* about such an unreal situation? This is one of the differences between physics and engineering. In physics, we think about such cases because they help us arrive at and understand general principles. Part of the role of a physics teacher is to help students appreciate this and enjoy the process. It helps if we have a playful attitude toward these thought experiments, and if we engage our students as co-conspirators in this playfulness.

II. RELATIVE MOTION – LESSON 1

A. OVERVIEW OF THE LESSON (MOTION RELATIVE TO SOLID SURFACES)

The anchor situation for these lessons is that of a person running on a flat bed truck or train that is itself in motion. In all the examples in these lessons, the questions involve measurements by an observer stationary with respect to the Earth. We have found that most students' intuition is correct for this case, even though many of them have never run on a truck or a train.

After all the possibilities for motion along one direction have been discussed (running toward the front and the back of the train; slower, faster, or at a speed equal to that of the train), the lesson proceeds to the two-dimensional case: running perpendicular to the direction of motion of the train.

It is appropriate in this lesson to introduce or re-introduce vector notation. Thus, students can see that vector addition gives the same result as their correct intuitions.

The homework assignments for this and subsequent lessons include questions about displacements and distances traveled in some time interval. These require of students a synthesis of their new learning about relative motion and of applications of the equations of kinematics learned earlier in their physics course.

B. MATERIALS

1.) Toy tractor or truck (slow constant speed, battery powered)

2.) Large sheet of newsprint or thin plywood

3.) Voting sheets

4.) Homework sheets - Relative Motion - Day #1

C. OBJECTIVES

1.) The student should be able to solve relative velocity problems about objects moving on top of a solid surface that is also moving.

2.) The student should be able to visualize the motion from the Earth frame of reference and from a frame of reference moving with respect to the Earth's surface.

D. **CONCEPT DIAGRAMS - RELATIVE MOTION - DAY #1**

1.) Motion relative to solid surfaces in one dimension

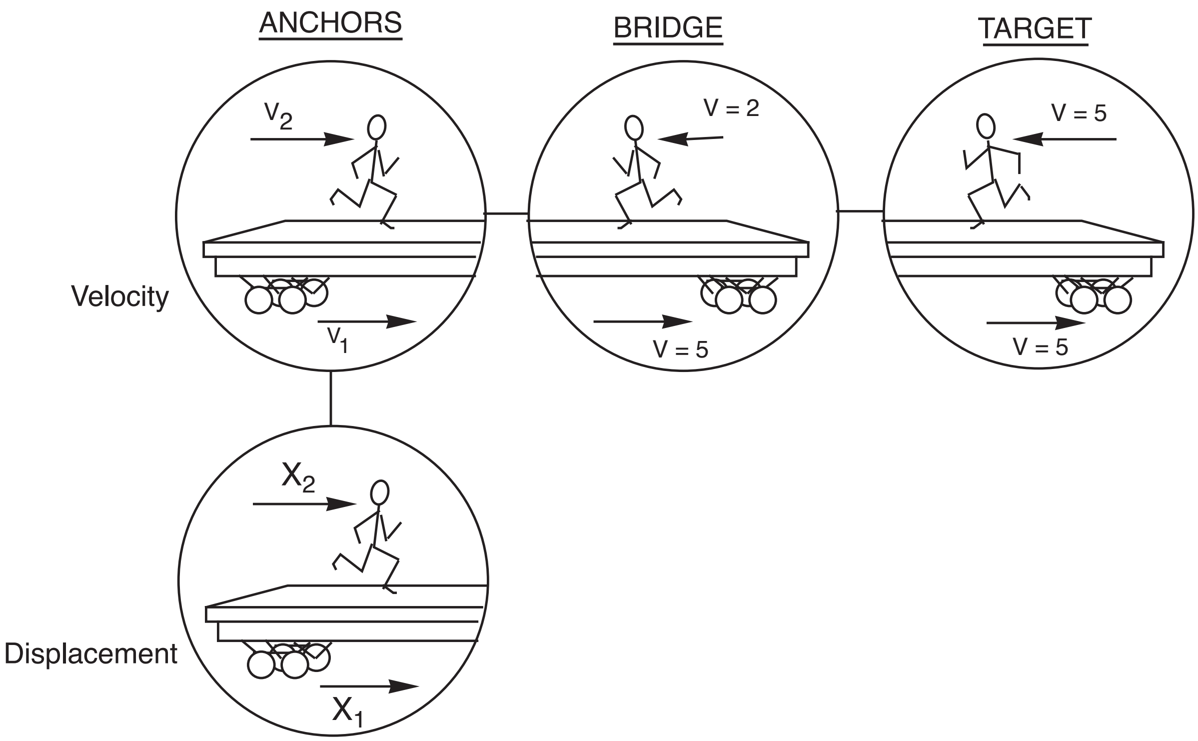

Figure 2.4

2. Motion relative to solid surfaces in two dimensions

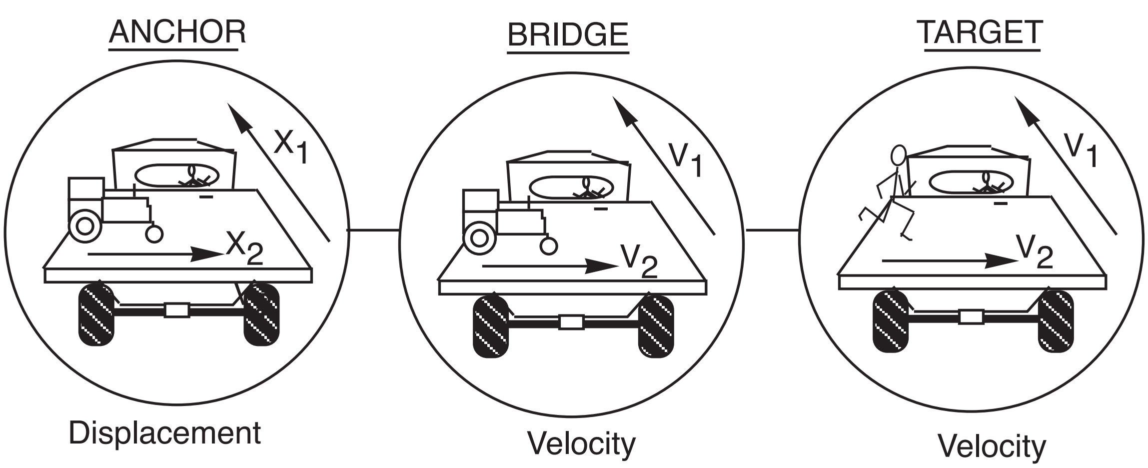

Figure 2.5

E. LESSON PLAN - RELATIVE MOTION - DAY #1

1.) Pass out the homework sheets and voting sheets

2.) Introduce the anchor problem

a.) Explain what the velocities mean. The train is traveling East at five meters/sec and Adam is running on top of the train at two meters/sec. That is Adam would be going two meters each second if he were running *this hard on* the ground.

b.) Clearly identify the two observers (Charlie and Lucy). Use names of students in the class to promote student interest and engage students in the discussion.

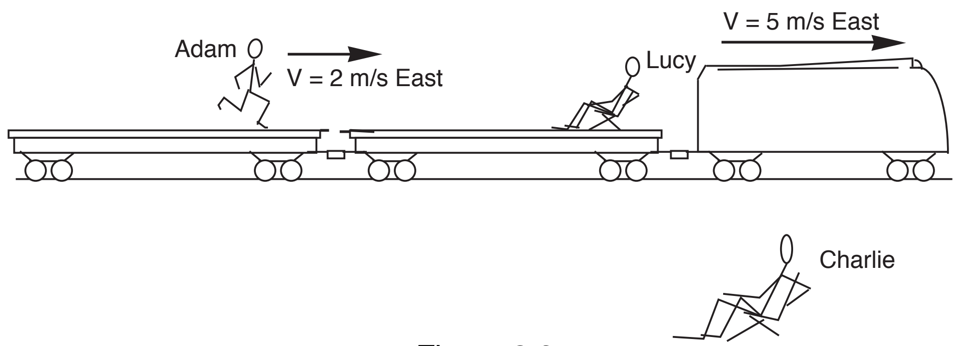

Figure 2.6

c.) Vote on the anchor problem

Vote #1 question:

- What is Adam's velocity as seen by Charlie?

d.) Discussion of Vote #1:

- How fast does Lucy see Adam moving?
- How fast does Charlie see Lucy passing?
- What part of this situation does or does not make sense?
- How could you convince someone that didn't believe you?

e.) If some people are having trouble,[1] consider a displacement example (consider distances covered in ten seconds as seen by both observers).

[1] Students who have trouble here are sometimes concerned about the "wind effect" or perhaps motion of the train while Adam's feet are up in the air.

3.) New problem running backwards

a.) Change the diagram to show Adam runs two m/s *west* with respect to the same train (Figure 2.7).

b.) Ask how fast each observer sees the others moving.

c.) Be sure to probe to see *what students think this will look like* from the Earth frame of reference (Charlie's viewpoint).
It may be helpful to have a student demonstrate the motion.

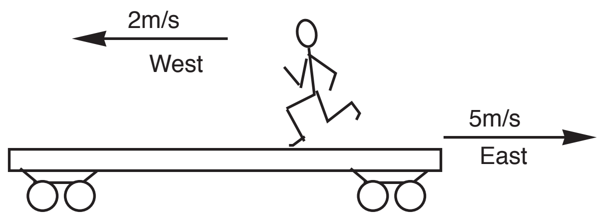

Figure 2.7

4.) Introduce the cancellation situation

a.) Change the diagram to Figure 2.8.

Adam runs five m/s *west* with respect to the same train.

b.) Vote #2 question

What is Adam's velocity from Charlie's point of view?

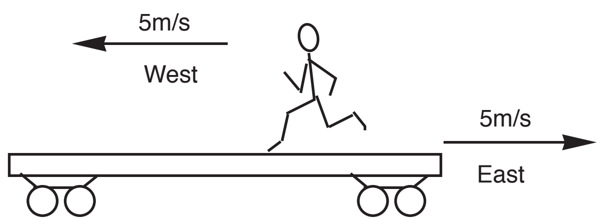

Figure 2.8

c.) Discuss the same questions used earlier.

5.) New problem running backwards faster (optional)

a.) Adam runs *seven m/s west* with respect to the train.

b.) Discuss this problem as time permits.

6.) Running across the train

a.) Change the diagram to show that Adam faces north and runs across the train at five m/s with respect to the train.[2]

b.) Vote #3 question

What is Adam's speed as seen by Charlie?

(Top View)

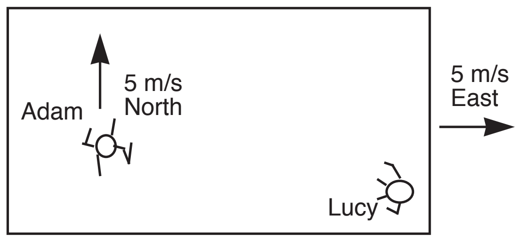

Figure 2.9

c.) Discussion:

- What velocity does each observer see?
- How would you convince someone who did not believe you?

7.) Demonstration (Toy vehicle driving on moving paper)

a.) Set up a constant speed toy driving slowly forward toward Lucy on a moving sheet of large paper or wood, with both moving in the same direction. Discuss how the *displacements* add in this situation. Then show how the *velocities* add in the same way.

b.) Demonstrate the cancellation situation discussed earlier (toy moving opposite to the paper motion) showing the moving toy remains stationary relative to the Earth.

[2] Be careful to indicate to the class that the picture has changed to a top view.

c.) Next, point the moving toy perpendicular to the motion of the paper (see Figure 2.10) and show how it moves diagonally relative to the ground. Help students see that the displacement and velocity relative to the ground may be found by vector addition. A diagram drawn on the demonstration paper is especially helpful.

d.) Finally, *draw a line across* the paper and show that the toy follows the line perpendicular to the velocity of the paper. Draw in an observer (Mary) watching from the end of the line on the paper. As the demonstration is repeated ask what direction the toy is moving from Mary's point of view. Then ask how to find the direction the tractor is moving relative to the students standing in the room. It is probably helpful to have the students note that the vehicle is <u>pointed</u> in one direction but moving in another direction as seen from their point of view.

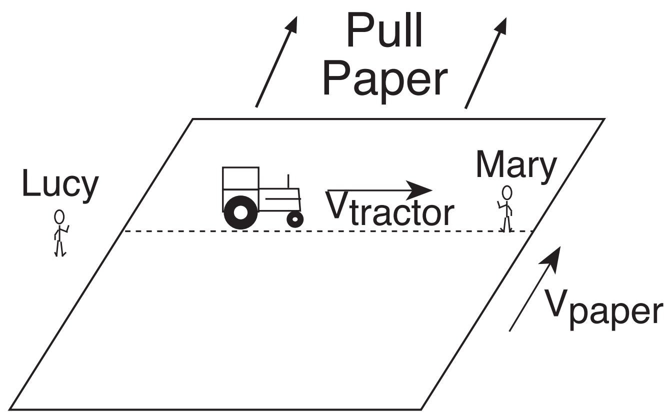

Figure 2.10

8.) <u>Assign homework</u>

Homework - Relative Motion - Day #1

F. TEACHING NOTES - RELATIVE MOTION - DAY #1

It seems to be very important early in this lesson to make clear what is meant by the idea of Adam's velocity "with respect to the train." Try to give as many supporting examples as possible to get everyone on board here. Phrases such as "Adam's speed if the train were standing still" or perhaps "the speed he would be going if running on the ground" will help some students catch on to this idea. The question "*How you would convince someone who does not believe these velocities add ?*" often brings out good student-generated examples and helps students find the courage to share their analogies and their uncertainties.

Some teachers feel that the examples in this lesson should use a big flat bed truck rather than a train. This is a matter of teacher preference as some students have very little exposure to trains.

During this lesson students often contribute observations from their experiences with escalators or moving walkways. The teacher may wish to suggest these ideas if students do not introduce them.

If students continue to have real trouble, it is always possible to drop back to the most concrete anchor situation and rephrase a particular velocity question as a displacement question.

It may help to ask students to pretend the train moves for one second and then Adam runs for one second. What would the result be? This trick may help some students with the two dimensional case. It is assumed in these matters that students have been introduced to addition of vectors (at least displacement vectors) before the lesson. If that is not the case, some work on vector notation and vector addition techniques would be needed between Day #1 and Day #2 in this unit.

Try to be alert for the problem that some students have with Adam running on the train. Some feel the train moves ahead of Adam while he has his feet in the air as he is running. It may be helpful to ask how the results would be different if Adam "race walked" (keeping one foot on the train at all times) instead of running on the train. Usually a few students need to examine this issue carefully to realize that the train does not move out from under the runner while both feet are in the air.

Some students will worry about the effects of air resistance or wind affecting the runner on the train. The teacher should emphasize the fact that we are using slow speeds in our example to avoid this problem.

The demonstration at the end of this lesson is very important for some students to help them grasp the basic concept of relative motion in this unit. Such a brief demonstration is only a starting place for many students. The laboratory activity suggested between Day #2 and Day #3 is designed to give students the chance to experiment with many situations in the demonstration environment.

III. RELATIVE MOTION LESSON – LESSON 2

A. OVERVIEW OF THE LESSON (MOTION RELATIVE TO MOVING LIQUIDS)

The standard problem situation in this lesson is that of a powerboat in a river with a uniform current. The correct view of this situation is much less intuitive for students than in the case of running on a flat car, because you slice through the medium (water) rather than moving relative to the surface of a solid identifiable object.

The lesson suggests using the flat-car situation as an anchor. Ask the students to discuss how the flat car and river problems are alike and how they are different. The students need to come by themselves to the conviction that the two situations are analogous. If you simply tell them, you may deprive them of the chance to build the intuition that is so important to really knowing physics.

Both some humor and some careful reflection is introduced by the bridging analogy of a boat and inner tube in a swimming pool on a moving flat car. Ask students in what ways this is similar to and different from a power boat in a river, and running on a flat car.

You may also want to make use of students' experience: some may recall differences in effort and results in rowing or swimming upstream, downstream, and across a stream. They will not have numerical data, but the qualitative information gained from swimming against a strong current can be memorable.

B. MATERIALS

1.) Voting sheets (perhaps the same sheets as Day #1)

2.) Homework sheets - Relative Motion - Day #2

3.) The "Vector River Activity" requires the following for each student group:

   a.) A large sheet of newsprint or cardboard

   b.) A slow-moving constant velocity toy vehicle

C. OBJECTIVES

1.) The student should be able to solve relative velocity problems about objects moving on a liquid medium.

2.) The student should be able to explain the relationships between different frames of reference.

3.) The student should be able to imagine an intermediate analogy (bridge) which will help visualize the way boats move on top of moving water.

4.) The student should be able to select the frame of reference which is most helpful when answering a given problem.

D. CONCEPT DIAGRAM - RELATIVE MOTION - DAY #2

1.) Motion relative to moving liquids

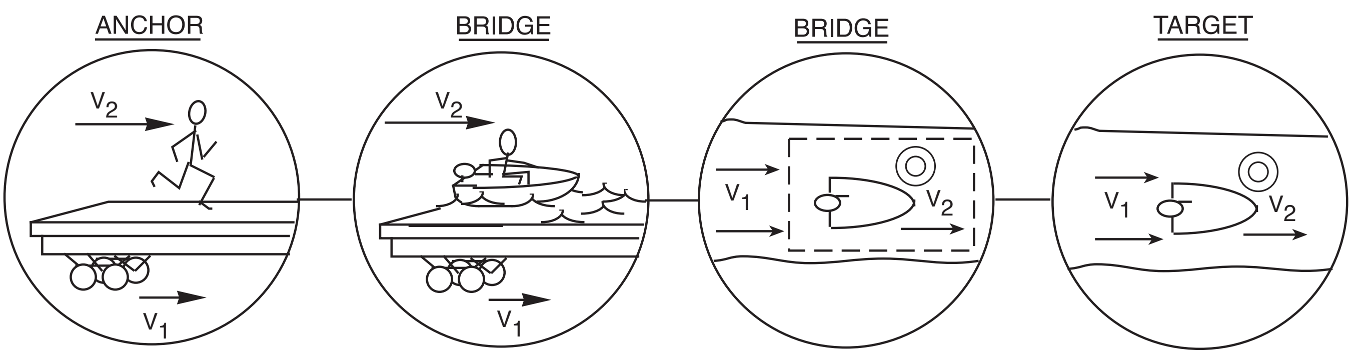

Figure 2.11

E. LESSON PLAN - RELATIVE MOTION - DAY #2

1.) Pass out homework sheets and voting sheets

2.) Discuss any questions about the homework from Lesson #1

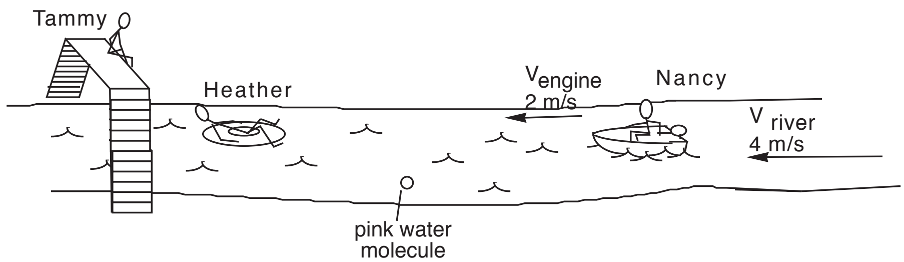

Figure 2.12

3.) Present the boat and river situation - Target problem

a.) Draw the picture explaining the labels. (Use your students' names)

b.) Explain carefully the meaning of V_{engine} and V_{river}.

The term V_{engine} means the speed the boat would be moving through still water such as a pond (the boat's speedometer reading, which measures how fast the boat passes the water molecules).

While V_{river} is often called the speed of the current, we can think of it as the average velocity of a typical water molecule.

c.) Vote on the target problem[3]

Vote #1 question:

From the bridge, how fast does Tammy see Nancy motor past? That is, how fast is Nancy moving relative to the ground?

d.) Encourage as many students as possible to contribute to the discussion. The teacher should try to remain neutral.

---

[3] Pair voting or some other variation on individual voting may be desirable for variety and increased student interaction.

e.) Discussion questions:

- How fast does Tammy see Nancy go by?
- How fast does Heather see Nancy go past?
- How fast does Heather see the pink water molecule pass?
- How fast does Nancy go past the pink water molecule?
- How fast does Tammy see Heather go past?
- Why is the speed of the boat with respect to the water different from the speed of the boat with respect to Tammy?

f.) Analysis questions:

- How is this situation similar to the train situation?
- How are the two situations different?
- Try to draw out from the students the notion that the water carries the boat just as the railroad car carries the person.

4.) <u>Present the *bridging analogy situation* (Figure 2.13)</u>

a.) Draw the picture of a swimming pool on a train.

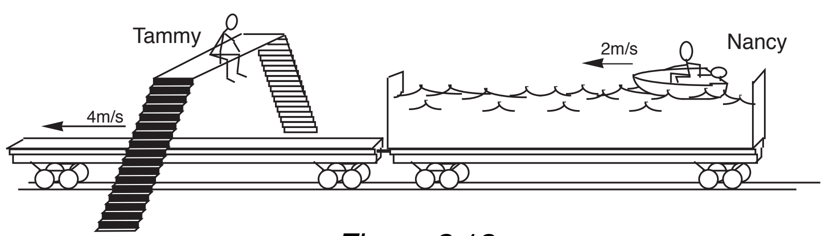

Figure 2.13

b.) Ask how this situation is the same as the river and how it is different from the river.

c.) Ask how the water feels to *Tammy* if she reaches down from the bridge to feel the water going past.

d.) Later add the innertube to the picture and ask how it would behave in the two situations.

5.) The boat motors up the stream

a.) Change the picture so Nancy points her boat *up stream* (East) at three m/s with respect to the water. Add East and West arrows to the picture at this point showing the current moving West and the boat pointed East.

b.) Ask about the motion from Tammy's point of view.

- What is Nancy's speed from Tammy's viewpoint?
- What is the inner tube's speed from Tammy's viewpoint?

6.) Present a more difficult up stream case

a.) Introduce Vote #2.

Nancy's boat is pointing up stream and is moving at 3 m/s relative to the water.

How fast does Heather, in the innertube, see Nancy approaching?

b.) The ensuing discussion usually produces a *serious struggle* for some students. Allow time for them to work through the situation.

The swimming pool on the train analogy may help, but some students have trouble because the walls of the swimming pool are in the water frame of reference while the bank of the river is in the Earth frame of reference.

7.) Discuss some other up stream cases

a.) Nancy travels 4 m/s East with respect to the water (the cancellation case).

Be sure to ask about the boat's velocity with respect to the innertube or the pink water molecule.

b.) Nancy travels 7 m/s East with respect to the water.

8.) Present the perpendicular situation

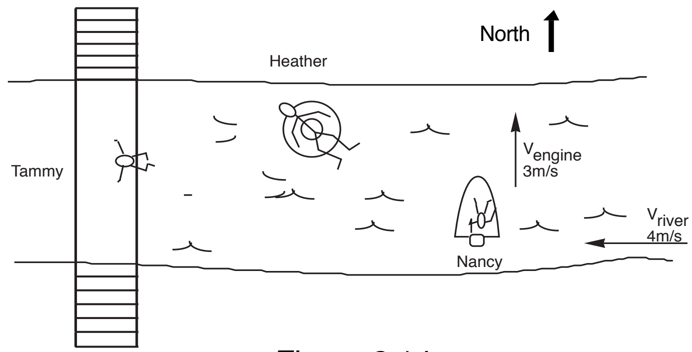

Figure 2.14

a.) Draw the new diagram, Figure 2.14, explaining clearly that the boat is pointed *North*, and noting that this is an overhead view.

b.) Vote #3 question about the perpendicular case.

With what speed does Tammy see Nancy's boat *moving*? That is, what is Nancy's speed relative to the ground?

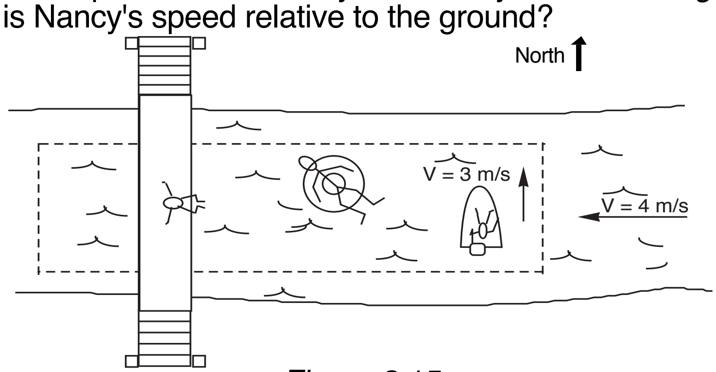

Figure 2.15

c.) During the discussion, remind students about the moving swimming pool idea by drawing a box in the river (Figure 2.15). This is a powerful reminder of the water as a frame of reference.

d.) Discussion questions: (refer to the “box of water” as needed)

- What velocity does Heather see the boat moving?
- What direction does Heather see the boat moving?
- What direction does Tammy see the boat **pointed**?
- What direction does Tammy see the boat **moving**?

e.) Encourage students to *draw a box* around the moving block of water in each problem to help them answer questions that can be easily answered in the water frame of reference.

9.) Assign homework

Homework - Relative Motion - Day #2

F. **TEACHING NOTES - RELATIVE MOTION - DAY #2**

Once again, it seems very important to distinguish clearly between the velocity relative to the river (water) and the velocity relative to the ground. Students who have difficulty may find the bridging example helps them connect back to the more concrete case of the solid surface in Lesson 1. Asking once more for students to offer analogies will help students who are struggling.

The discussion of the bridging example: the swimming pool on the train, should be helpful for some students. Those who have difficulty with the water frame of reference may especially benefit from the questions about the "special pink water molecule." Remind the class that the water supports the boat just as the train in Day #1 supported the runner. Some students may prefer to think of the analogy between the boat and the runner on the train.

At some time relatively early in the discussion it will be necessary to make it clear that we must assume that the current is the same everywhere in the river. Some students may be concerned that it varies as a function of depth so we must also assume a deep river.

Teachers of average classes should seriously consider adding an extra day to this sequence after Day #2. A careful discussion of the Day #2 homework and the "*Vector River Activity*" (see materials) will be of *real* value to many students. In order to find the time to properly help students deal with the questions of boats and rivers some teachers may find they prefer to carefully deal with boat problems and skip the materials about airplanes in the Day #3 lesson following this one.

Students frequently fail to see the advantage of using the water frame of reference as the easy viewpoint from which to answer questions. If you ask them to think about a swimming pool on a train, they can usually answer the following correctly:

- Is it easier to swim toward the front end of the train or the back end of the train if you want to swim 1 m/s relative to the water?
- What direction do you point your body if you want to get to the side wall of the pool as soon as possible?

However, many students find these questions very hard when asked in the context of a river. Remind them to draw a box around the block of water to help them visualize this point of view.

Some teachers may be uncomfortable with the use of a pink water molecule (or pink air molecule in Lesson 3) since molecules do not have stable colors. This is intended as a fanciful way to visualize a small element of water that one could imagine observing. You may wish to inform students of this or you may prefer to use a "flashing" or "blinking" molecule where the fanciful aspect is even clearer.

Another way to support these lessons is to send student groups to search the web for relative motion videos which demonstrate a motion viewed from two or more points of view (frames of reference).

IV. RELATIVE MOTION LESSON – LESSON 3

A. OVERVIEW OF THE LESSON

In this lesson we deal with an airplane moving in air that is itself moving, i. e. there is a wind. The correct interpretation is even less intuitive than for motion in a river. A plane is very powerful. In this case we are usually not even aware of any effects of air on our motion, because we move mostly on solid ground. We rely on friction in our soles or tires to convert our muscular exertion into motion, and it is much more powerful than the effects of the air we move through. Because the lesson is such a big step from Day #2, we strongly recommend an extra day for most classes to deal with the river problems and carry out the *"Vector River Activity"* in the materials section.

As a bridge to the anchor situation of the train, the lesson suggests the case of a model airplane flying inside a very long enclosed moving boxcar with transparent sides, so that an observer on the ground can see the plane inside. The propeller is pushing against the air in the boxcar, and the air is moving relative to the ground just as if there were a steady wind.

Some students will know that airplanes always take off and land *against* the wind direction ("into the wind"). You may want to use that knowledge and show that this practice reduces the length of runway needed to clear the trees or buildings at the end of the runway at takeoff. Care must be taken, however, to avoid lengthy excursions into related side issues when there are a number of students still struggling with the central concepts under examination. We need to help students internalize the notion that an airplane is supported by the air so the motion of the air is important.

B. MATERIALS

1.) Voting sheets

2.) Homework sheets - Relative Motion - Day #3

C. OBJECTIVES

1.) The student should be able to solve relative velocity problems about objects moving within an invisible fluid medium.

2.) The student should be able to visualize intermediate analogies through which one can make sense of relative velocity problems involving an airplane flying in the wind.

D. **CONCEPT DIAGRAM - RELATIVE MOTION - DAY #3**

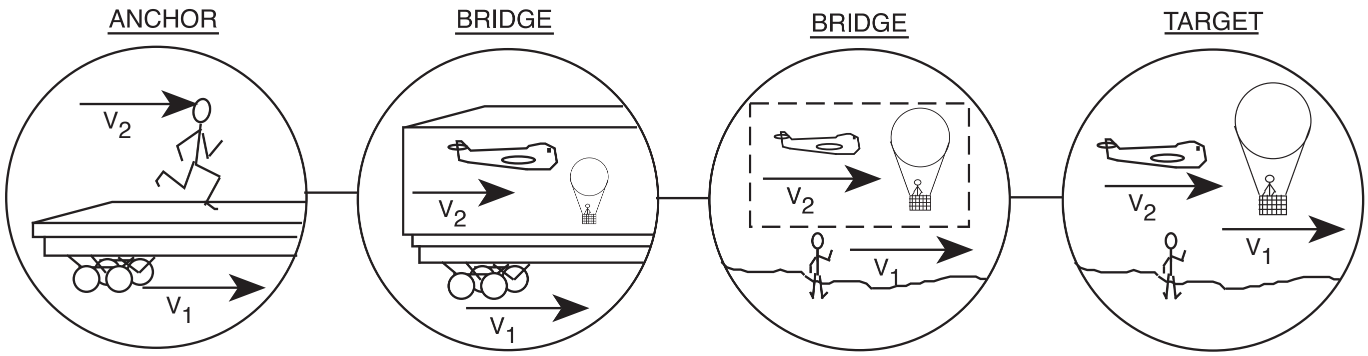

Figure 2.16

E. LESSON PLAN - RELATIVE MOTION - DAY #3

1.) Pass out homework sheets and voting sheets.

2.) Discuss any questions about the homework from Lesson 2 or the *"Vector River Activity"* if necessary.

3.) Introduce the new situation.

a.) Draw Figure 2.17.

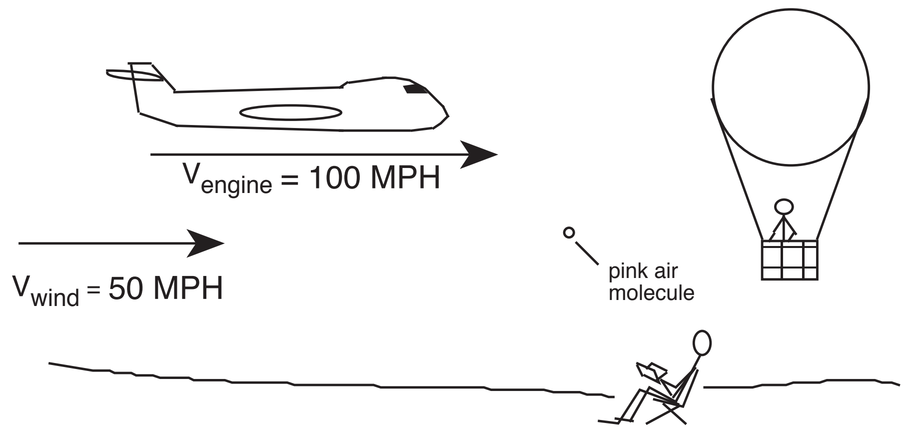

Figure 2.17

b.) Carefully explain the idea of 100 mph with respect to the air. This is the velocity (called the air speed) which measures how fast the plane passes the air molecules. It would also be the speed of the plane over the ground if the air were still. When velocity questions are introduced, East and West direction arrows should be added to the picture.

4.) Vote on the Target problem – (Vote #1)[4]

What is the speed of the airplane as seen by the person on the ground?

a.) Discussion suggestions

- Velocity of the balloon as seen by each observer
- Pink air molecule's velocity as seen by each observer
- Plane speedometer (air speed indicator) reading.
- How is this situation similar to the train?

4 A change in voting style may seem useful for variety in this lesson. (See the introduction to the book.)

5.) Introduce the bridging analogy (Figure 2.18)

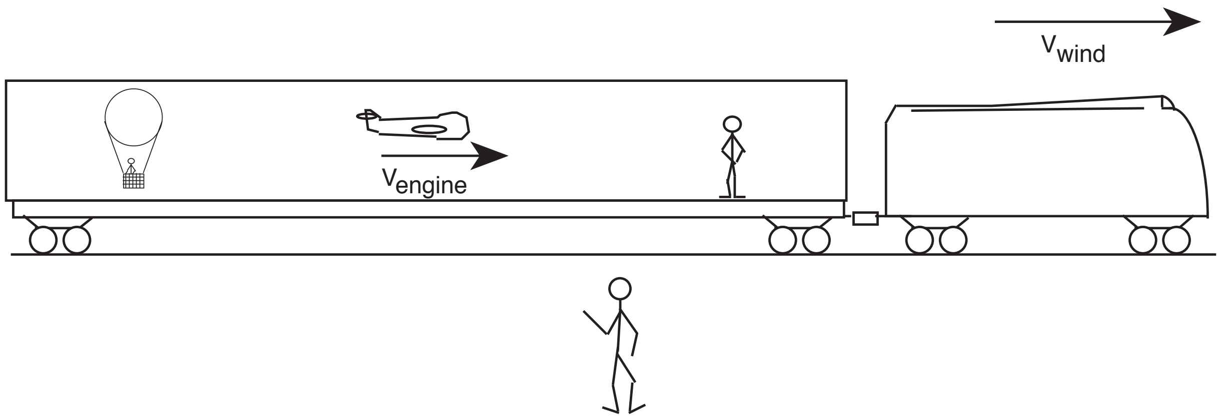

Figure 2.18

a.) Draw the diagram.

b.) Explain that we have a big railroad car with glass walls. Due to the walls, the people in the car do not feel any wind. Perhaps add a pink air molecule.

c.) Discuss how this situation is the same and how it is different from the original airplane problem.

6.) Change the original problem to consider the cancellation case

a.) Change the picture to indicate:

V_{wind} = 100 mph to the West
$V_{engines}$ = 100 mph to the East

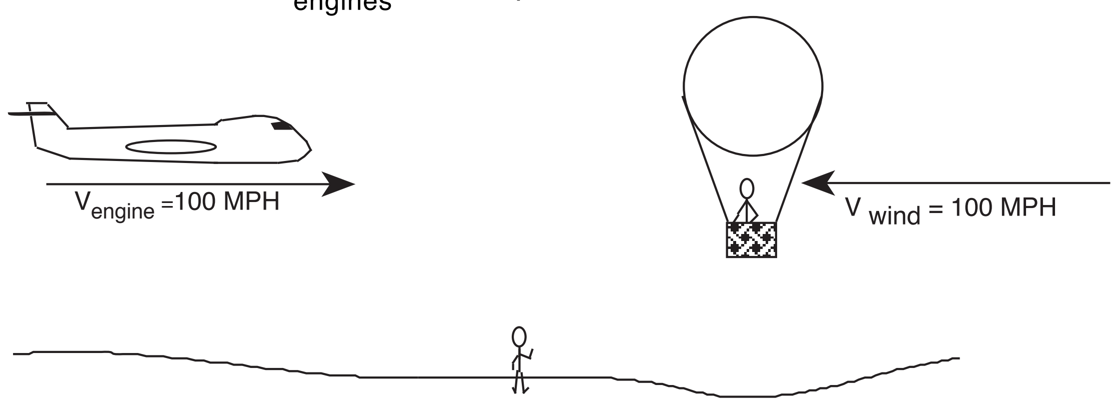

Figure 2.19

b.) Vote on the cancellation problem.

Vote #2 question:

What is the speed of the plane as seen by the person on the ground?

c.) Ask these questions:

- Velocity of the balloon as seen by each observer
- Pink air molecule's velocity as seen by each observer
- Plane speedometer (air speed indicator) reading.

d.) To stimulate controversy you might ask:

- Will the plane fall down?
- Would you stand under it?
- Will it run out of gas?
- How do you make sense of this situation?

e.) Modify the original airplane diagram by adding a box around a block of air as shown in Figure 2.20. Then ask students to explain how this "box of air" relates to earlier examples in the unit.

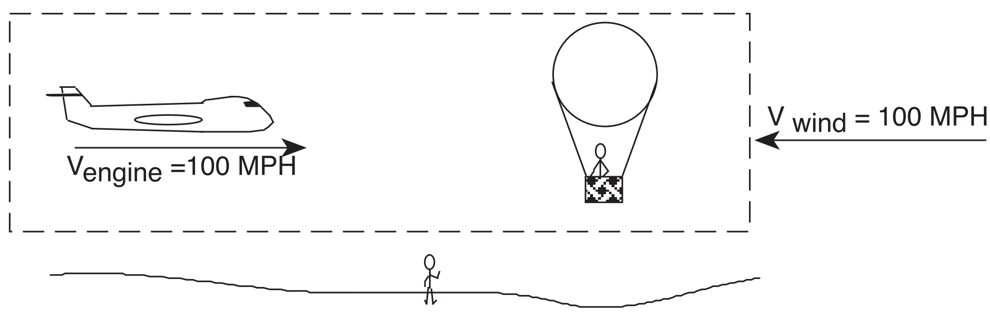

Figure 2.20

7.) Practice with a new problem

a.) Modify the picture as indicated:

V_{wind} = 150 mph West

V_{engine} = 100 mph East

b.) Use the same questions considered in section 6c.) above.

8.) <u>Introduce the perpendicular case</u>

a.) Draw Figure 2.21 (Note: This is an overhead view.)

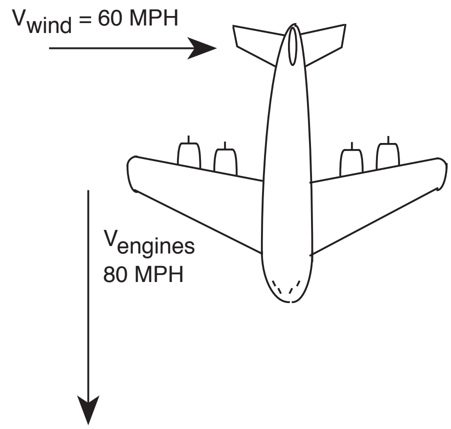

Figure 2.21

b.) Emphasize the fact that this is an overhead view.

c.) <u>Vote #3 question:</u>

What is the speed of the plane as seen from the ground?

d.) Follow up with the same questions considered earlier.

- Velocity of the balloon as seen by each observer
- Pink air molecule's velocity as seen by each observer
- Plane speedometer (air speed indicator) reading.

e.) Introduce a balloon, pink molecule, or “box of air” if these ideas seem helpful to the discussion.

9.) <u>Assign homework</u>

Homework - Relative Motion - Day #3 (Note: problems #7 and #8 are more difficult and may not be appropriate for all classes).

F. TEACHING NOTES - RELATIVE MOTION - DAY #3

Teachers of advanced level or honors classes may move on quickly from this material to vector navigation problems using either boats or airplanes. Exercises working with maps provide good extensions as one must clearly sort out map scales and the difference between velocity vector scales and the scale of the map. The more accelerated classes may work mostly with trigonometry, while average classes will probably benefit from vector addition work done with scale drawings.

If a teacher finds the airplane cases of the third lesson cause a great deal of trouble, it may be best to ignore the airplane cases and concentrate on building the strongest possible foundation with relative motion based on the first two days of this unit.

The use of descriptive labels on the vectors in this lesson is designed to build on the student's intuition. One should, however, notice that the lesson endeavors to shift to relative velocity terminology during the last part of the lesson and throughout the homework.

Teachers who wish to use only S.I. units should note that a number of problems in this lesson and in the homework use miles per hour. Thus, it may be necessary to touch up homework problems or quiz questions offered in this unit. The bearing angle system (clockwise from North) is used in many problems in this unit, because that system is widely used in orienteering, boat navigation, and airplane navigation. Teachers who wish to use the system found in some math and physics books (counterclockwise from the x - axis) should modify homework and quiz questions as needed.

An occasional student may raise the issue that the random microscopic motion of air molecules is far greater than the wind speed. If this concern is raised, you should assure the student that the "pink air molecule" is an oversimplified picture of a "lazy molecule" that is always at rest relative to the neighboring air molecules.

V. <u>MATERIALS FOR DUPLICATION</u>

A. Homework Problems

1.) Homework - Relative Motion - Day #1

2.) Homework - Relative Motion - Day #2

3.) Homework - Relative Motion - Day #3

B. Activity Sheets

1.) Vector River Activity

C. Quiz and Test Questions - Relative Motion

HOMEWORK - RELATIVE MOTION - DAY #1

Name: ____________________

Period: _____Date: __________

1.)

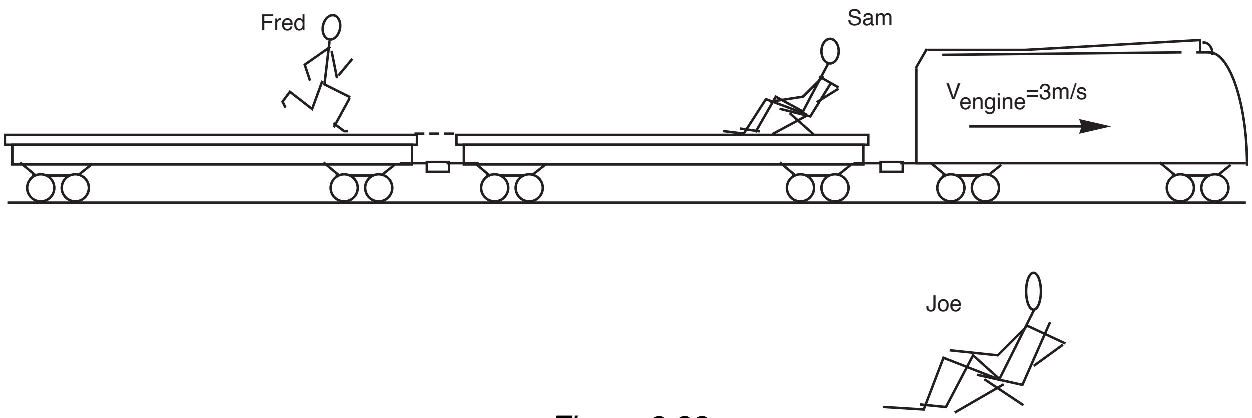

Figure 2.22

A long train of flat cars is traveling East at a steady speed of three m/sec. Fred is running at his standard rate of five m/sec on the flat cars toward the front of the train. Sam is watching from his chair on the flat car.

Answer the following questions including units and directions on vector quantities.

a.) During a 10 second period how much closer does Fred get to Sam?

____

b.) With what velocity does Sam see Fred approaching?

____

c.) Find Fred's displacement during the ten second period as seen by Joe.

____

d.) With what velocity does Sam see Fred approaching?

____

e.) What is Fred's velocity as seen from Joe's point of view?

____

2.)

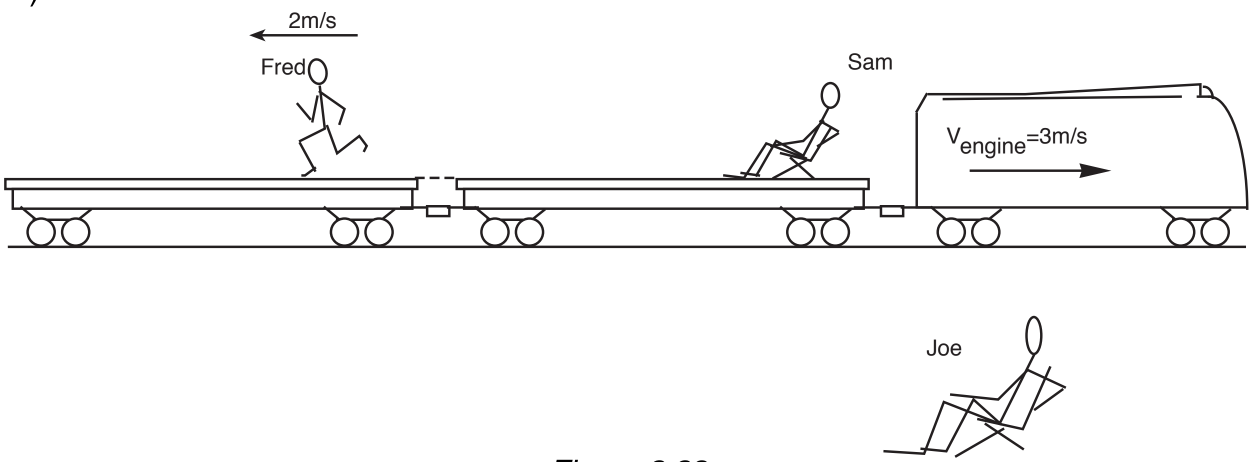

Figure 2.23

After reaching the front of the train Fred turns around and jogs toward the rear of the train, at a steady two m/sec. Answer the following questions including units and directions on vector quantities.

a.) During a 10 second period how much distance does Fred travel as seen by Sam?

____

b.) What is Fred's displacement, during the 10 second period, as seen by Sam?

____

c.) During the ten second period find Fred's displacement as seen by Joe.

____

d.) With what velocity does Sam see Fred moving? ________________________

e.) What is Fred's velocity as seen from Joe's point of view? ________________________

f.) Explain why Fred's walking looks funny from Joe's viewpoint?

____

____

3.)

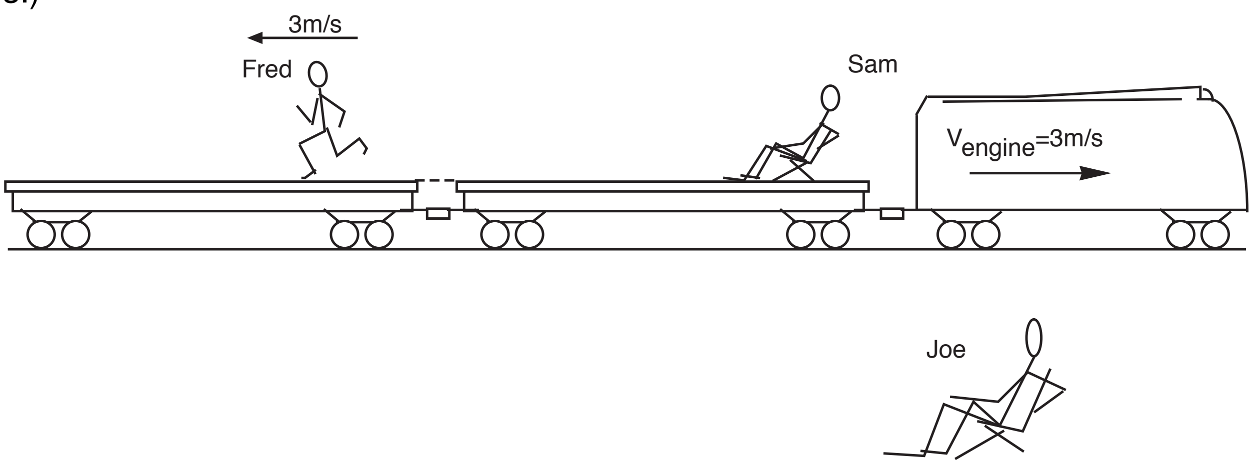

Figure 2.24

Now Fred tries jogging toward the rear of the train at a speed of three m/sec.

Answer the questions below.

a.) During a 10 second period how much distance does Fred travel as seen by Sam?

____

b.) Find Fred's displacement during a ten second period as seen by Joe.

____

c.) With what velocity does Sam see Fred moving?

____

d.) What is Fred's velocity as seen from Joe's point of view?

____

e.) What does Fred appear to be doing from Joe's point of view?

____

4.)

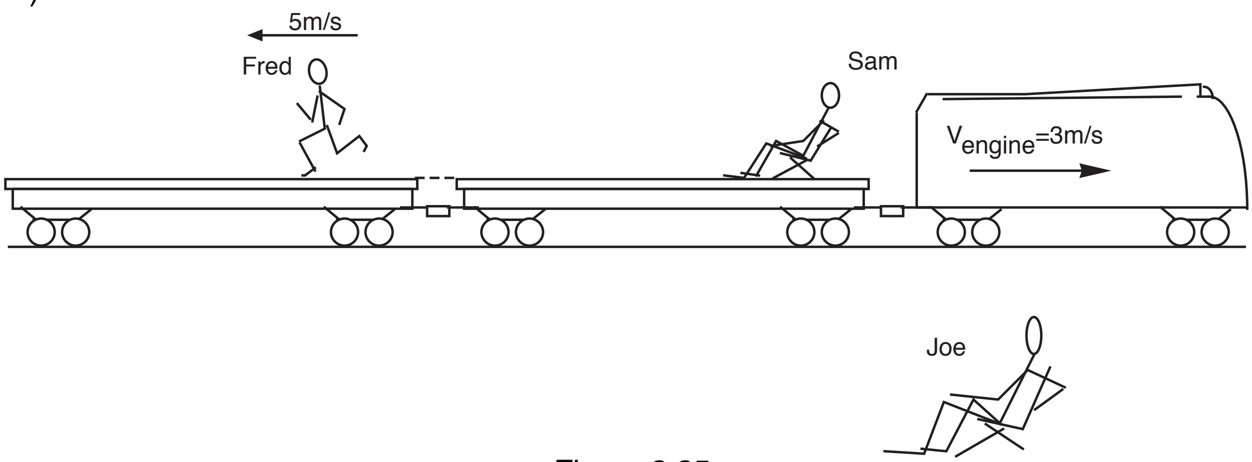

Figure 2.25

Having regained his ambition, Fred starts running toward the rear of the train at his original five m/sec.

a.) Determine Fred's displacement with respect to the train during a 10 second period. ____________________

b.) What is Fred's displacement with respect to the ground during the 10 second period? ____________________

c.) Find Fred's velocity with respect to the train. ____________________

d.) Find Sam's velocity with respect to the ground. ____________________

e.) Find Fred's speed with respect to the ground. ____________________

f.) What is Sam's speed with respect to the train? ____________________

5.) Fred gets bored and decides to try running across the train. He faces North and runs at a steady speed of 4 m/sec for five seconds. Construct a neat and clearly labeled vector diagram as needed.

a.) Draw a sketch below showing an overhead view of the train with vectors sketched for Fred's velocities as seen by Sam and Joe.

b.) Find Fred's speed with respect to the train. ____________________

c.) Find Fred's distance with respect to the ground. ____________________

d.) Find Fred's velocity with respect to the train. ____________________

e.) Find Fred's velocity with respect to the ground. ____________________

f.) Find Joe's velocity with respect to Sam. How do you need to change your thinking to answer this question?

____

6.) Go back and check:

Did you include a magnitude and a direction on all of your *vector* answers?

7.) Finally, Fred faces toward bearing 40 degrees (40 degrees East of North) and walks diagonally across the flat car at a speed of 2 m/sec for a period of 5 seconds. Include a neat and clearly labeled vector diagram below. Then determine the values indicated below.

a.) Fred's speed with respect to the train. ____________________

b.) Fred's distance with respect to the ground. ____________________

c.) Fred's velocity with respect to the train. ____________________

d.) Fred's velocity with respect to the ground. ____________________

e.) Joe's velocity with respect to Sam. ____________________

HOMEWORK - RELATIVE MOTION - DAY #2

Name: ____________________

Period: _____Date: __________

1.) A wide river flows from North to South at a steady rate of 2 m/sec. The motor boat has been tested on a calm pond and it was found that it goes through the water at eight m/sec.

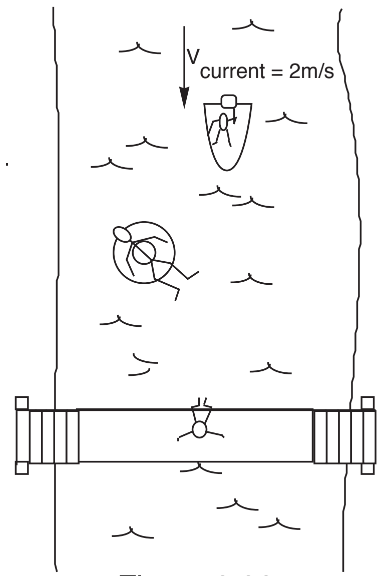

Figure 2.26

a.) During a five second period *how much distance* does the boat move over the water as seen by the person in the inner tube.

____

b.) Find the boat's *displacement* as seen by the observer watching from the bridge for five seconds.

____

c.) What is the *velocity* of the boat relative to the inner tube?

____

d.) What is the velocity of the boat as seen from the bridge?

____

e.) What is the velocity of the inner tube as seen from the bridge?

____

2.) Consider the situation in Question 1 when the boat's engine is <u>not</u> running. Determine the following:

a.) Velocity of the boat with respect to the inner tube. ________________

b.) Velocity of the boat with respect to the water molecules. ________________

c.) Velocity of the boat with respect to the ground. ________________

d.) Velocity of the inner tube with respect to the ground. ________________

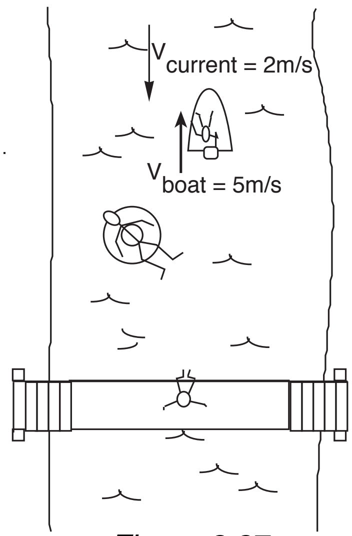

Figure 2.27

3.) If the boat in Question 1 turns around (points North) and travels five m/s through the water molecules find:

a.) Velocity of the boat with respect to the inner tube.

____

b.) Velocity of the boat with respect to the bridge.

____

c.) Displacement of the boat with respect to the ground during a ten second period.

____

4.) If the boat slows down until it is heading North with a speedometer reading of 2 m/s, find:

a.) Velocity of the boat with respect to the inner tube.

____

b.) Velocity of the inner tube with respect to the boat.

____

c.) Velocity of the boat with respect to the ground.

____

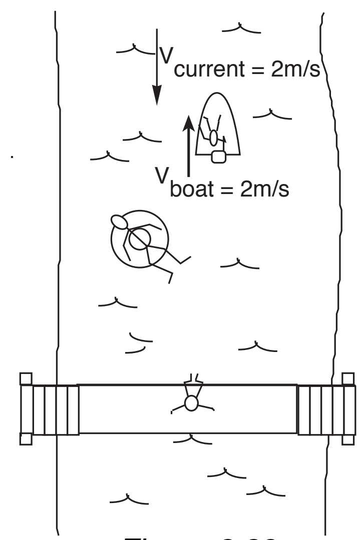

Figure 2.28

5.) After landing on the East shore, the boat points due West and travels 5 m/s with respect to the water. Make a diagram of this situation including a box around the block of water in the river.

a.) Determine how wide the river is if the trip to the West shore requires 10 seconds. (Hint: think about the swimming pool.)

____

b.) Velocity of the boat with respect to the river. ______________________

c.) Velocity of the boat as seen from the bridge. ______________________

d.) Distance the boat is swept down stream (South) while the boat is making the 10 second crossing.

____

e.) Distance the inner tube travels with respect to the ground during the 10 seconds.

____

6.) The boat wishes to leave the East shore and travel at five m/s with respect to the water so that it will move *directly* across the river and land on the opposite shore without sliding down stream. Add a neat and clearly labeled velocity vector diagram within the picture.

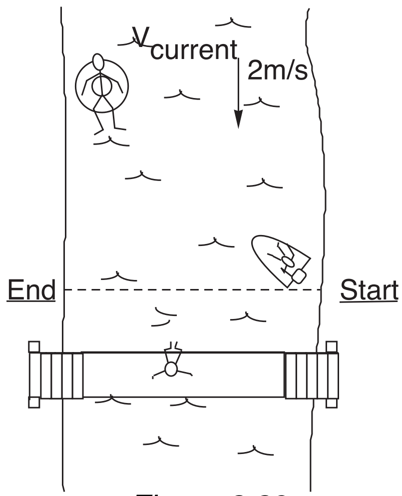

Figure 2.29

a.) Determine the correct bearing angle so the boat can move directly across on the dotted line.

____

b.) Find the velocity of the boat with respect to the ground.

____

c.) How much time is required to make the crossing (width found in Problem 5)?

____

d.) Find the speed with which the inner tube sees the boat pass.

____

e.) What is the velocity of the boat relative to the water?

____

f.) If the boat wants to pick up the person in the inner tube, which way should it point?

- To the right of the inner tube.
- Straight toward the inner tube.
- To the left of the inner tube.

HOMEWORK - RELATIVE MOTION - DAY #3

Name: ____________________

Period: _____Date: __________

1.)

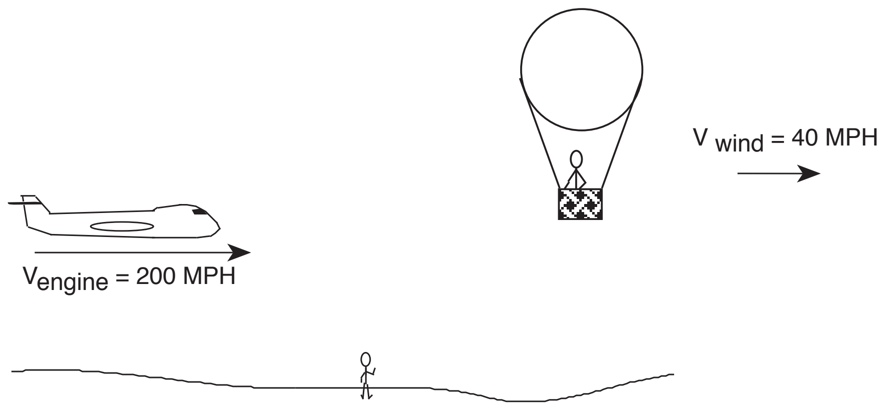

Figure 2.30

An airplane is flying pointed directly East with a speed of 200 mph relative to the air. That is, it would be going 200 mph in still air. If the wind is blowing toward the East at 40 mph find each of the following:

a.) Velocity of the plane with respect to the air. ______________________

b.) Speed of the plane with respect to the ground. ______________________

c.) Velocity of the plane with respect to the balloon. ______________________

d.) Displacement of the plane with respect to the ground in 2.5 hours. ______________________

2.) If the wind remains unchanged but the plane in Question 1 turns and flies straight West at the same 200 mph air speed, find each of the following:

a.) Reading of the plane's air speed indicator. ______________________

b.) Velocity of the plane with respect to the ground. ______________________

c.) Velocity of the plane with respect to the balloon. ______________________

d.) Distance the plane travels with respect to the ground in 5.0 hours. ______________________

e.) Velocity of the balloon with respect to the air. ______________________

3.) The plane from Question 1 flies pointed straight *North* at an air speed of 200 mph and the wind is unchanged (toward the East at 40 mph), find each of the following:

a.) Velocity of the plane relative to the air. ____________________

b.) Speed of the plane relative to the ground. ____________________

c.) Velocity of the balloon with respect to the ground. ____________________

d.) Displacement of the plane relative to the ground during 3.5 hours.

____

4.)

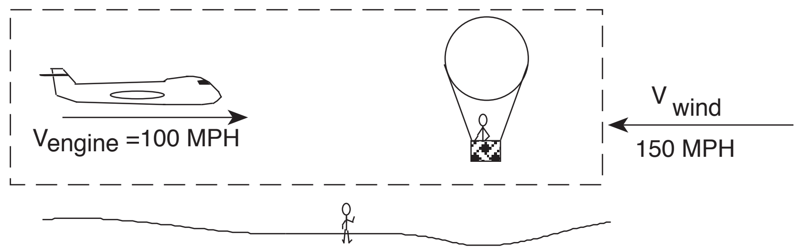

Figure 2.31

The pilot decides to slow down her engines to save fuel so the plane is now going only 100 mph East with respect to the air. Unfortunately the wind picks up to 150 mph West as shown above. Determine the following:

a.) Velocity of the plane with respect to the air. ____________________

b.) Velocity of the plane with respect to the ground. ____________________

c.) Speed with which the pilot sees the balloon approaching, that is, velocity of the balloon with respect to the plane.

____

d.) Displacement of the plane with respect to the ground in 2.5 hours.

____

e.) Describe what this looks like to our observer on the ground. Will the plane fall down?

____

____

5.) When you are in the balloon and the wind is still 150 mph toward the West;

a.) How fast do you feel the air is going by? ____________________

b.) How would a flag fly from the balloon? (What direction would it blow toward?)

____

c.) If you were going for a balloon ride, would you wear a thick, fluffy coat for warmth or a tight wind breaker to keep out the wind?

____

6.) If the plane shown below flies at the same 100 mph air speed with a bearing of 20 degrees (20 degrees East of North) and the wind is now from the East at 100 mph, answer the following. Include a neat and clearly labeled vector diagram.

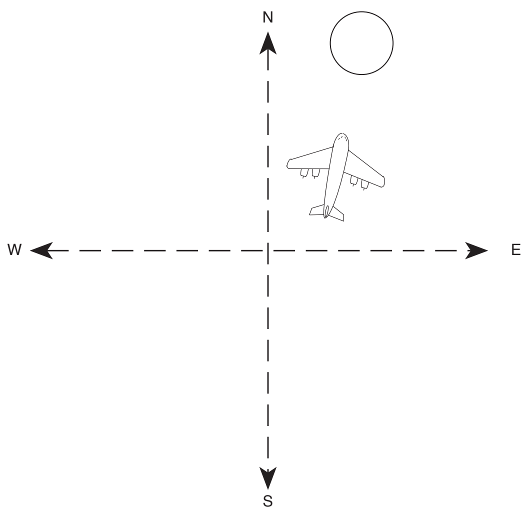

Figure 2.32

a.) Velocity of the plane with respect to the air.

____

b.) Velocity of the plane with respect to the ground.

____

c.) Speed with which the pilot sees the balloon approaching.

____

d.) Displacement of the plane with respect to the ground in 2.5 hours.

____

e.) Draw a "box of air" around the plane and the balloon. If the pilot sees the balloon straight ahead and 50 miles away, should the pilot turn a little right, a little left, or go straight in order to meet the balloon?

____

7.) If your plane is traveling with a velocity of 140 mph through the air pointed at a bearing of 320 degrees and the wind is blowing 50 mph toward a bearing of 80 degrees, answer the following. Include a neat and clearly labeled vector diagram.

a.) Speed of the plane relative to a balloon. ______________________

b.) Velocity of an air molecule (pink) with respect to the plane. ______________________

c.) Speed of the plane with respect to the ground. ______________________

d.) Displacement of the plane with respect to the ground in 1.8 hours. ______________________

8.) A pilot wished to fly to an airport located *due North* of his present location. The plane is flying at 150 mph relative to the air and the wind is from the East (toward the West) at 60 mph. Answer the following. Include a neat and clearly labeled vector diagram.

a.) Bearing at which the plane is pointed. ______________________

b.) Velocity of the plane with respect to the ground. ______________________

c.) Velocity of the balloon with respect to the plane. ______________________

d.) Displacement of the plane with respect to the ground during a 2.5 hour trip. ______________________

e.) Explain why this problem is harder than the earlier problems.

VECTOR RIVER ACTIVITY

Name: ____________________

I. PREPARATION

Period: _____Date: __________

- Assume your constant velocity vehicle travels at approximately 0.4 m/s.
- Practice "pulling" the sheet of newsprint to simulate a constant current in your "river" of approximately 0.3 m/s.
- Draw an inner tube and pink water molecule in your "river".
- Attach a piece of tape on the lab table (or floor) next to the sheet of paper to represent a stationary observer on shore.

II. PROCEDURE

In order to help you visualize the relative motion between a boat and a river, a river and the shore, and ultimately the boat and the shore; simulate the conditions in *each* of the following situations. (Assume your river is flowing due South.)

A. BOAT AT FULL SPEED HEADING DOWNSTREAM

1.) What is the velocity of each of the following with respect to (as seen by) an observer on the shore?

_____________________ pink water molecule

_____________________ inner tube

_____________________ boat

2.) What is the velocity of each of the following with respect to (as seen by) a person in the inner tube?

_____________________ pink water molecule

_____________________ boat

_____________________ person on shore

Describe a situation in which the observer in the inner tube:

a.) *sees a person on shore stationary with respect to the inner tube*

b.) *sees a person in the boat stationary with respect to the inner tube*

3.) What is the velocity of each of the following with respect to (as seen by) an observer in the boat?

_____________________ pink water molecule

_____________________ inner tube

_____________________ person on shore

B. **BOAT AT FULL SPEED HEADING UPSTREAM**

1.) What is the velocity of each of the following with respect to (as seen by) an observer on the shore?

_____________________ pink water molecule

_____________________ inner tube

_____________________ boat

How must the speed of the current compare with the boat's speed relative to the water so that an observer on the shore would see the boat moving upstream?
____

Downstream? ____

2.) What is the velocity of each of the following with respect to (as seen by) a person in the inner tube?

_____________________ pink water molecule

_____________________ the boat

_____________________ person on shore

3.) What is the velocity of each of the following with respect to (as seen by) an observer in the boat?

_____________________ pink water molecule

_____________________ inner tube

_____________________ person on shore

What velocity of the boat will cause the person on shore to appear stationary as seen by an observer in the boat? ____________________

C. **<u>BOAT AT FULL SPEED HEADING ACROSS THE RIVER AT A 90 DEGREE ANGLE</u> (<u>ASSUME THE BOAT IS POINTED WEST</u>.)**

1.) What is the speed of each of the following with respect to an observer on the shore?

_____________________ pink water molecule

_____________________ inner tube

_____________________ boat

2.) What is the speed of each of the following with respect to (as seen by) an observer in the inner tube?

_____________________ pink water molecule

_____________________ boat

_____________________ person on shore

3.) What is the speed of each of the following with respect to (as seen by) an observer in the boat?[1]

_____________________ pink water molecule

_____________________ inner tube

_____________________ person on shore

[1] Question 3 (in each section of this activity) is the most difficult for students.

III. DETERMINE THE BEST ANSWER FOR THE TWO SITUATIONS BELOW

A. Assume you fell overboard in the middle of the river directly across from the dock where all your friends are waiting for you. Which *general* direction should you swim so that you can climb out of the water onto the dock? Draw two arrows in the picture with one showing the direction the swimmer's effort and the other showing the direction of the swimmer's path relative to the shore. Label each arrow clearly.

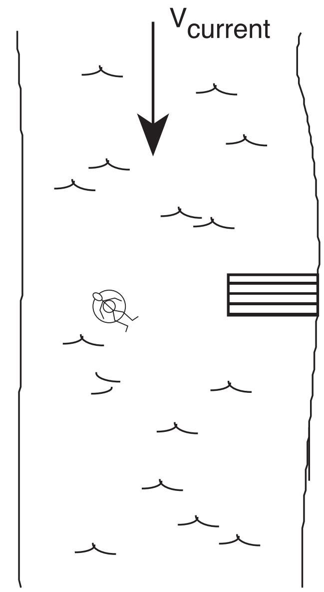

Figure 2.33

B. Assume you fall overboard in the middle of the river again, but this time no one is waiting to greet you. What general direction should you swim to reach the East shore in the *shortest time possible*? (Hint: Think of how you would swim in a swimming pool on a train to get to the side of the pool in the shortest time.) Draw two arrows in the picture again as in the problem above, and label the two arrows clearly.

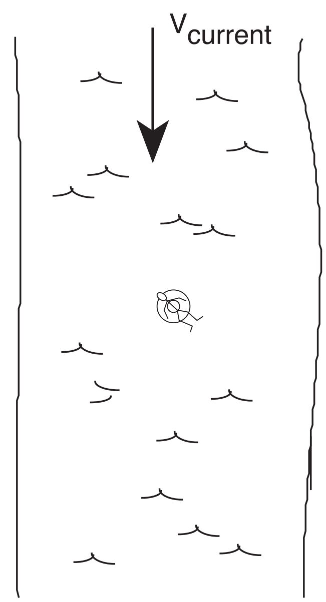

Figure 2.34

IV. <u>CREATE YOUR OWN BOAT PROBLEM</u>

Make up an example in which the boat is not parallel or perpendicular to the current. You should keep the speed of the boat and the current the same as those used in the earlier problems. Draw the picture clearly labeled in the space given. (You may need to make a scale drawing of your vector diagram or solve your problem with trigonometry.)

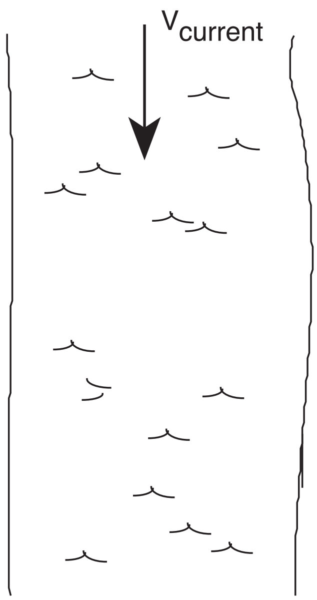

Figure 2.35

1.) What is the velocity of each of the following with respect to an observer on the shore?

______________________ pink water molecule

______________________ inner tube

______________________ boat

2.) What is the velocity of each of the following with respect to an observer in the boat?

______________________ pink water molecule

______________________ inner tube

______________________ person on shore

3.) What is the velocity of each of the following with respect to an observer in the inner tube?

______________________ pink water molecule

______________________ boat

______________________ person on shore

QUIZ AND TEST QUESTIONS - RELATIVE MOTION

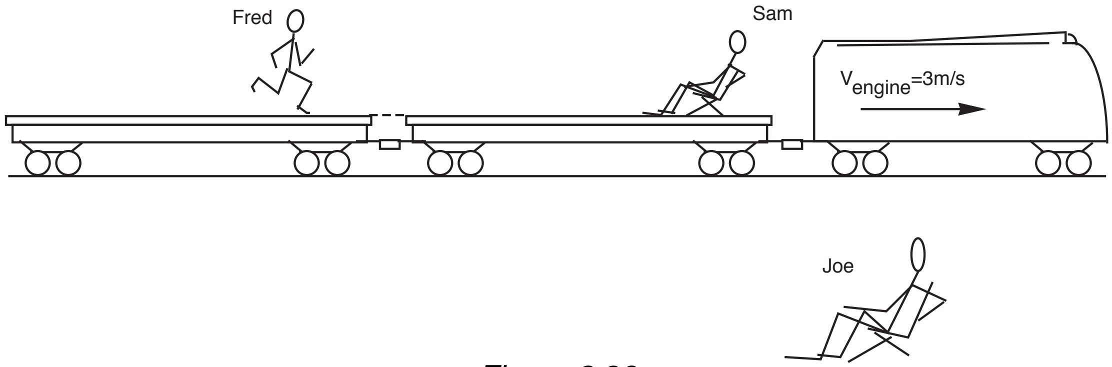

Figure 2.36

1.) A long train of flat cars is traveling East at a steady speed of three m/sec. Fred is running at his standard rate of four m/sec on the flat cars toward the front of the train. Sam is watching from his chair on the flat car.

a.) During a five second period how much distance does Fred travel from Sam's point of view?

____

b.) Find Fred's displacement during a five second period as seen by Joe.

____

c.) With what velocity does Sam see Fred moving? ______________________

d.) What is Fred's velocity as seen from Joe's point of view?

____

e.) What is Sam's velocity with respect to Joe? ______________________

2.) A river is flowing toward the East with a five m/s current. A motor boat points West and goes at a rate of three m/s with respect to the water.

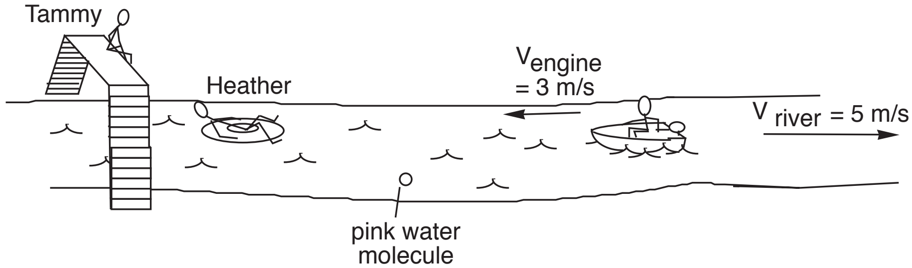

Figure 2.37

Determine the following:

a.) Velocity of the inner tube with respect to the ground. ____________________

b.) Velocity of the inner tube with respect to the water. ____________________

c.) Velocity of the boat with respect to the ground. ____________________

d.) Speed of the water molecules with respect to the boat. __________________

e.) Speed of the boat relative to the inner tube. ____________________

f.) If the person walks toward the front of the boat at two m/s relative to the boat, determine the velocity of the person relative to the ground.

____

g.) The boat sinks and the person must swim to shore to avoid death by cold exposure in the cold water. The person needs to reach shore in the *shortest possible time*. The South shore is nearest and it does not matter where the person reaches the shore, for the goal is to reach land as soon as possible. The swimmer's body should be pointed:

- West of South
- directly South
- East of South
- due West

3.) The plane in this problem was flying East at an air speed of 150 mph against a headwind of 80 mph, but is scheduled to arrive much too early. The pilot decides to fly slowly to save fuel so the plane is now flying 100 mph East with respect to the air. Unfortunately the wind picks up to 120 mph West as shown below.

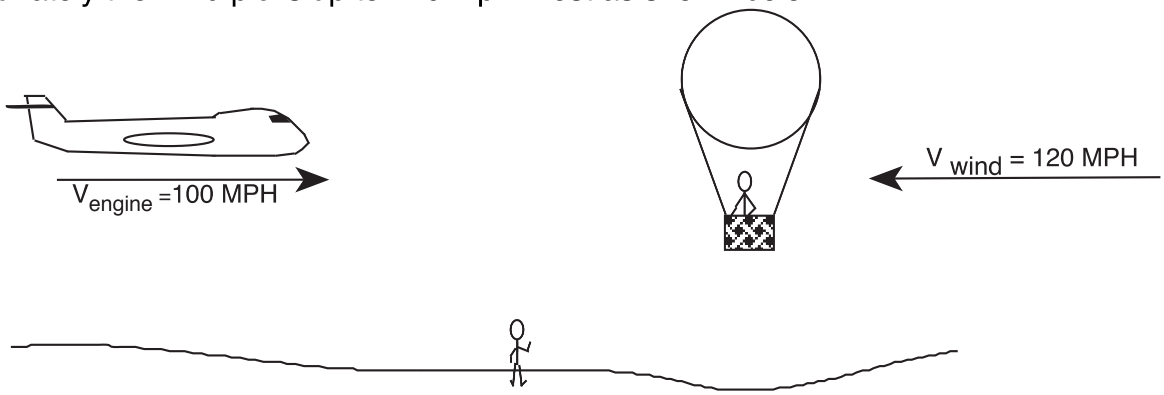

Figure 2.38

Determine the following:

a.) Velocity of the plane with respect to the balloon. ____________________

b.) Velocity of the plane with respect to the ground. ____________________

c.) Speed with which the plane's pilot sees the balloon approaching. __________

d.) Displacement of the plane with respect to the ground in 3.5 hours.

____

e.) Displacement of the plane as seen from the balloon during a period of 2.0 hours.

____

f.) The reading on the air speed indicator inside the plane. __________________

g.) The time required for the plane to reach an airport located 100 miles to the East.

____

4.) A plane is flying with a speed of 200 mph relative to the air with its nose pointed 70 degrees East of North (bearing 70 degrees). If the wind is blowing *toward* due West at 60 mph, find the following with an accurate and carefully labeled *scale drawing* or by *trigonometric methods* showing your method clearly.

a.) Velocity of plane with respect to the ground. ______________________

b.) Velocity of the plane with respect to the air. ______________________

c.) Distance the plane travels relative to the ground during a 2.5 hour period. ______________________

d.) Bearing angle of the path the plane follows over the ground. ______________

5.) Consider a swimmer in the river who wishes to take a rest. Is it easier for her to swim 10 meters up stream to an inner tube or 10 meters down stream to an inner tube?

a.) The preserver upstream.

b.) The preserver downstream.

c.) Both require the same effort.

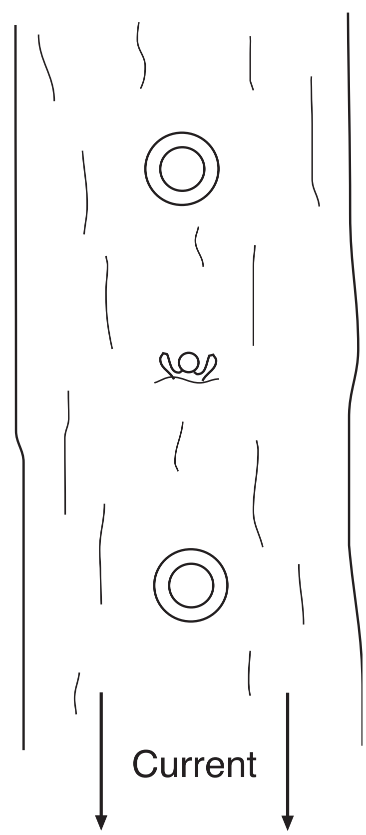

Figure 2.39

UNIT 3

Surface Friction Forces

UNIT #3 - SURFACE FRICTION FORCE

I. OVERVIEW OF THE SURFACE FRICTION FORCE UNIT

A. MAJOR PRECONCEPTIONS WHICH POSE DIFFICULTIES IN THIS UNIT

1.) Friction is not a force, but some sort of influence that interferes with motion.

2.) Friction does not act in a particular direction.

3.) The magnitude of the surface friction force on a static object is greater than the net force applied to the object parallel to the surface.

B. GENERAL STRATEGY OF THIS UNIT

In trying to analyze and solve mechanics problems, students often fail to include friction forces altogether, have them pointing in the wrong direction, or fail to have them reverse direction when the direction of motion changes. Research has shown that some students do not know (or believe) that there *is* a specific force due to friction, let alone know its direction or its magnitude relative to other forces in a problem. Most students have a vague intuitive notion about friction: it plays a role in causing sliding objects to slow down and stop; sometimes it generates heat; and it causes loss of useful energy. These ideas serve them well in everyday life, and are useful building blocks, but the concept of friction as a force with a particular direction is often missing.

If students are to be able to correctly analyze mechanics problems that include friction, they first need to have a *qualitative understanding* that: 1.) friction is a force exerted on each of two interacting objects, 2.) it has a direction and magnitude, and 3.) Newton's third law applies to friction forces, as it does to all forces between two bodies. Once these concepts are firmly established and students are convinced of them at an intuitive level, mathematical operations (such as using coefficients of friction) should be easy for them. We find that this unit on friction forces helps bring about that intuitive understanding.

As in the previous lessons, we make use of analogies - more specifically of anchors and bridges - to help students build useful intuitions. This unit plan about friction also calls for occasional votes by the students and for class discussion after each vote.

Static situations are considered first. Once students have acquired a strong intuitive understanding of static friction, the lesson plan shifts to friction situations with moving objects.

C. CONCEPT DIAGRAM - SURFACE FRICTION

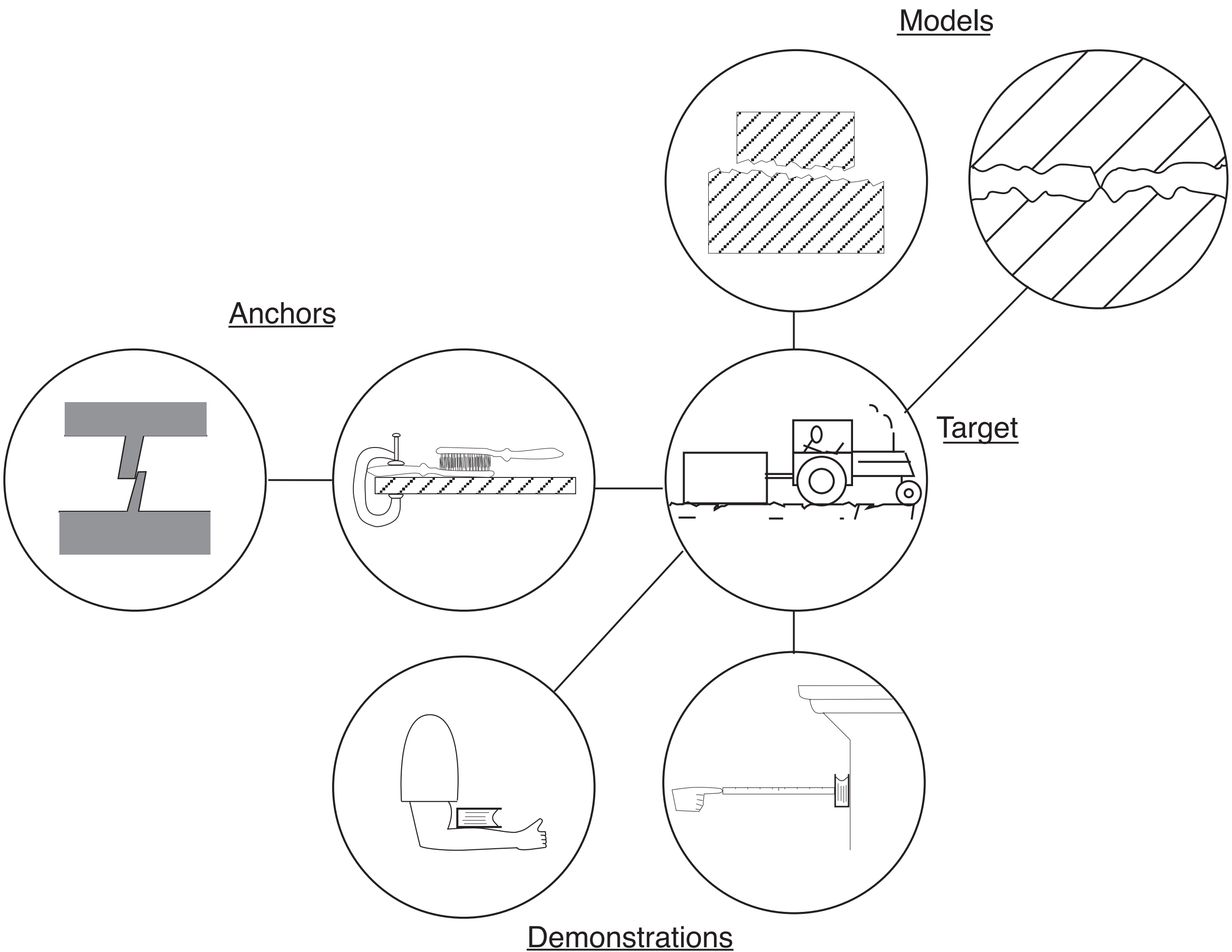

Figure 3.1

D. **THE PHYSICIST'S VIEW**

Considering that friction acts just about everywhere and all the time, and that without it almost all familiar kinds of motion would be impossible, friction does not usually receive much attention in the mechanics curriculum. One reason is that a full treatment of friction is very complicated. However, in introductory physics, the goal of most teachers is not so much to teach what friction "really" is as to teach students a simplified model sufficient to handle certain problems in mechanics. To make these problems challenging but not impossible, we assume an idealized description of friction: the frictional force between two solid objects is independent of the area of contact and of their relative speed (except for speed zero, i.e. static friction), and it is proportional to the normal force of each object on the other.

The first over-simplified model of friction in the lesson plan describes surfaces, even those that are smooth to the eye and touch, as quite rough on a smaller scale. When one object slides across another, the lumps (called "asperities") on each surface protrude partially into the valleys of the other (Figure 3.1), so that the sliding motion is in fact a very rough ride. The bumps bend as they collide and sometimes break each other. Like all models, this one has shortcomings, but it *is* visualizable. That is one of its advantages as a starting point for teaching.

The situation in real materials is considerably more complicated. For example, asperities can come close enough together to form "welds" or chemical bonds. The breaking of these bonds is then an important factor in the friction force especially for clean metal surfaces (Sherwood, 1984).

However, the oxide film which forms on most metals can completely destroy metal-metal bonds. If this type of adhesion is low, a considerable part of the friction comes from "ploughing" of the bumps through the other surface, similar to the way in which a wire brush might leave groves in clay when dragged across it. It can also come from "repeated distortion and recovery of surface cell-structure" (Tabor, 1981, p. 176). In the latter case, energy is dissipated by vibrations from these distortions and recoveries spreading into the solid.

Helping students move from simplified to more complex models. However, we should not be distracted by these interesting complications from the main difficulty: many students do not even consider frictional resistance to be a force, and even when they do, they do not share the basic conception of the direction of this force with the physicist. Although chemical bonding is the largest mechanism of frictional force in some situations, it is a rather counter-intuitive mechanism for friction. And, since it also causes adhesion forces perpendicular to the surface it may further confuse the issue of the direction of frictional forces parallel to the surface. We therefore suggest starting with an over-simplified model of colliding asperities (bumps) in order to help students visualize the presence, horizontal direction, and equality of the opposing frictional forces. Once these ideas are in place, we modify and elaborate the model, with the above mechanisms (in the tradition of scientific method). Thus, this is a developmental strategy for helping students move from a simplified to a more complex model rather than a "present everything at once" strategy.

This is a bit like moving from the Rutherford model of the atom to more complex models. It is important to help students realize that mental models are only models. The atom is not a miniature solar system, but in some ways it acts like one. There are some similarities, and there are some differences. The similarities enable us to "see" the atom in new and helpful ways. The differences remind us that *all* models have limitations.

The anchor situation in this lesson is two brushes, with their bristles interleaved, one being pulled across the other, as in Figure 3.1. Presenting it as a class demonstration makes it easier for students to visualize. Surface friction is not exactly the same as two brushes rubbing against each other, but in some important ways it acts like that, making it a useful starting point. If some students do not agree that the bottom brush exerts a horizontal force opposing the motion of the top brush, a simpler anchor is suggested in the form of two "single bristles" colliding. The lesson then attempts to make it plausible that the surfaces in the target problem also exert horizontal forces on each other. Two demonstrations are included to help to support this conclusion.

Thus this lesson plan relies heavily on *mental models* - visualizable models that help us understand one phenomenon or concept by analogy to another, more familiar one. Most students are greatly helped in their learning by having mental models proposed to them. It is not always true that the same mental model works equally well with students as with experts in the field, because of their vastly different experiential base. As teachers with content goals, our task is to find and use mental models that students find compelling while at the same time moving them closer to the expert's view.

Some teachers may feel that the inclusion of friction in the dynamic case adds more issues than one can deal with in an average class. Since this lesson is offered under the assumption that most students have not dealt with inertia, it is certainly possible to consider only the static friction case by skipping sections 11, 12c, and 13 of this lesson.

References

Jonathan Reichert, “How did friction get so ‘smart’?,” *Phys. Teach.* **39,** 30 (Jan. 2001).

Sherwood, W. H., (1984), "Work and Heat Transfer in the Presence of Sliding Friction", *American Journal of Physics*, Vol. 52, pp. 1001-1007.

Tabor, David, (1981), "Friction - The Present State of Our Understanding", *Journal of Lubrication Technology*, Vol. 103, pp. 169-179.

II. SURFACE FRICTION LESSON

A. MATERIALS

1.) two wire brushes

2.) "C" clamp

3.) non-slippery book and meter stick

4.) dynamics cart and a 250g or 500g mass with flat surfaces

5.) (optional) air table with large and small disk

6.) two spring scales

7.) pre-instruction quiz

8.) voting sheets

9.) homework sheets

B. OBJECTIVES

1.) Students should understand that there are different kinds of resistive forces.

2.) Students should be able to identify the direction of resistive forces, especially between solid surfaces.

3.) Students should be able to identify the direction of the reaction (third law) force during an interaction involving friction.

4.) Students should be able to distinguish between resistive (friction) forces and weight.

C. LESSON PLAN - SURFACE FRICTION UNIT - DAY #1

1.) Pass out pre-instruction quiz (tractor problem)

a.) Explain that this does not count on their grade.

b.) Collect the quiz when they are done.

2.) Pass out voting sheets

3.) Discussion of the pre-quiz

a.) Ask for various opinions on the tractor problem. Perhaps call on weaker students first.

b.) Make a free body diagram on the board. Try not to reveal the right answer about what the floor is doing. Show the students' suggested answers on the diagram.

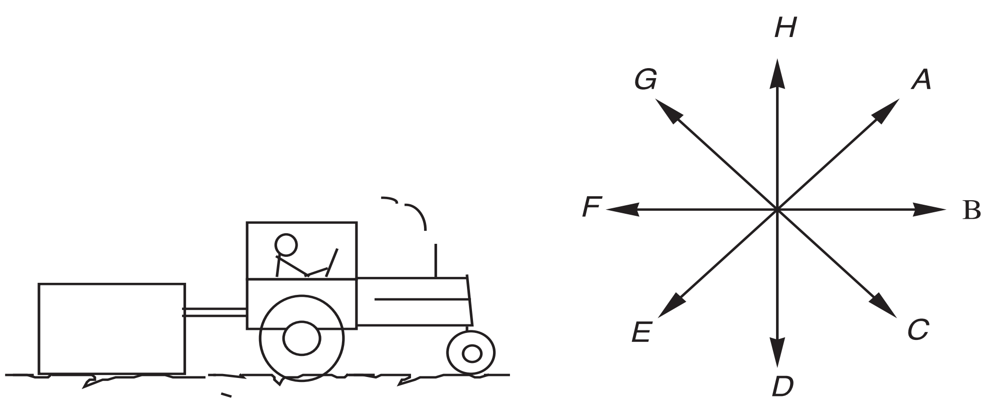

Figure 3.2

4.) Introduce Vote #1 (the target problem)

a.) Vote #1 Question:

What is the direction of the friction (resistive) force alone exerted on the block? Draw in choices exactly as above.

b.) Write the letter of one force vector as your answer.

5.) Demonstration

a.) Present the anchor situation with the wire brushes. Pull the top brush enough to make the deflection of the bristles clear to the class, implying that a force is exerted on both brushes.

Toothbrushes might be used instead of wire brushes, although the bristles on the wire brushes are larger and easier to see.[1]

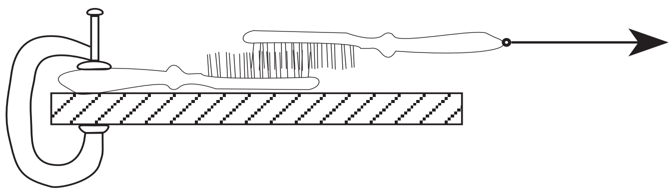

Figure 3.3

b.) Vote # 2 Question

Using the directional diagram in the Pre-Instruction Quiz, indicate the direction of the force applied by the bottom brush.

c.) Discussion question:

• What are the forces “felt” by each of the brushes? In what direction do those forces act?

6.) Introduce the "bumps" model.

a.) Consider a rough block that someone is trying to drag across a rough floor. What would a magnified view of the surfaces look like? Offer the diagram suggested below.

b.) Note: We are not pulling hard enough to move the block.

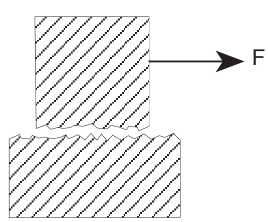

Figure 3.4

c.) *Discussion question:*
What is the direction of the friction force acting *on each surface?*

[1] The teacher may choose to pass out pairs of toothbrushes and use as a class activity.

7.) <u>Compare the two friction forces</u>

a.) If students are successfully conceptualizing the forces and their associated directions, then introduce the *equality question* about the opposing forces.

b.) Ask "which force is larger, the force of the block pushing sideward on the floor or the force of the floor pushing sideward on the block?"

8.) <u>Individual bumps model</u>

a.) Consider a magnified view of two flexible bumps trying to pass each other, but stuck in this bent position. Each bump might be viewed as a single bristle or a spring. Consider the top bump (bristle) to be stronger (stiffer).

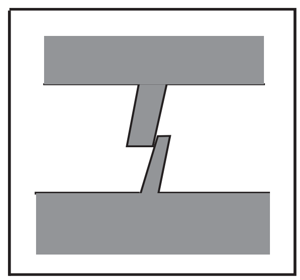

Figure 3.5

The teacher may wish to demostrate this with two flexible plastic rulers, or other similar objects.

b.) Discussion:

- What are the directions of the opposing forces?
- Consider the equality issue for the opposing forces.
- How could they possibly be *equal* if one bump (spring) is stronger? (Recall work with strong and weak springs from Unit 1.)

9.) Repeat vote on the target problem

a.) Vote #3 Question:

What is the direction of the friction force exerted on the box? (same choices).

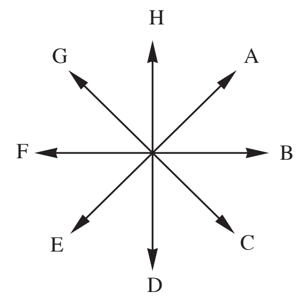

Figure 3.6

b.) Comment to the class that this is a repeat vote so each person's makes sense score is very important.

10.) Book on the forearm demonstration with a student volunteer

This demostration may be introduced as an aid for those students who remain skeptical, or as reinforcement for the class.

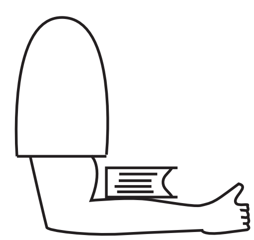

Figure 3.7

a.) Place a book on the student's forearm resting on the table. Pull the book toward the hand, while pressing down so the book sticks and does not slide. (Note: A sticky or rough book is desirable.) Talk to the student about the sideward deflections and the normal compression of the skin on the arm as you tug on the book.

After demonstrating on one student, have each pair of students try this process on each other. Urge them to try to feel both the friction component and the normal component of the force from the book. Should some students ask if these two forces may be considered a single force, the discussion in the end of the Teaching Notes may prove helpful.

b.) Questions for the class discussion:

• What is the direction of the force exerted on your arm?
• What is the direction of the force your arm exerts on the book?

c.) <u>Challenge</u> the class with this question:

Since the book is harder, how could the forces possibly be equal? Perhaps ask for analogies or earlier examples that help students make sense of the equality. Compare the force of the book on the arm versus arm on book. If the class does not bring it up, recall the rubber fire hydrant from the Normal Forces Lesson in Unit 1.

11.) <u>Consider the dynamic case with the tractor pulling the box at a slow and steady speed.</u>

Ask the students how motion affects friction.
What happens to friction forces when an object is moving over a surface? How does this compare to the static case, when there is a force on an object, but it does not move across a surface?

a.) Add a velocity arrow to the tractor picture from the Pre-Instruction Quiz.

b.) Demonstrate with the wire brushes (moving slowly).

c.) Ask about the *bumps model* (Introduced earlier). Does it work in this situation?

d.) How are the forces different when the box is moving?

12.) Demonstration showing the equal and opposite friction forces

a.) Set up the arrangement shown in Figure 3.8.[2]

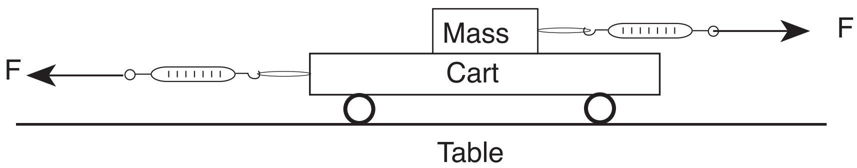

Figure 3.8

b.) *Static case demonstration*

• *Demonstrate the low friction interaction* between the cart wheels and the table (show how it glides).
• Ask students to predict which of the two friction forces between the cart and the mass will be larger.
• Discuss which of the volunteer students will be measuring the friction force on the bottom of the mass and which will feel the friction force acting on top of the cart.
• Then place the mass on the cart as shown and *gradually increase the two forces* applied and compare readings without motion.
• What must the friction forces be like at the surface between the cart and mass?
• Draw diagrams of the cart and mass separately if needed to emphasize the one interface where there is friction.

c.) *Dynamic case demonstration*

• Ask students to predict which force will be larger if one object slides past the other.
• Hold one scale stationary and slowly move the other so that the mass slides slowly over the cart continually reading the scales as the objects slide.
• Then reverse the process and pull the cart from under stationary mass.
• Try to emphasize the presence of the equal and opposite friction forces, but be advised that students may remain puzzled as to why forces are equal at this time (see Teaching Notes).
• Observe the maximum friction force value just before the mass starts to slide and compare it to the value when the mass is slowly sliding.
• Teachers of advanced classes, who have already used force probes, may consider their use in these demonstrations.

---

[2] There is negligible friction force between the wheels of the cart and the table so we can compare the friction forces between the cart and the mass. The cart, or two together, should have a long top.

An air table with two different size pucks may be used in place of the cart and mass.

13.) <u>Introduce the vote on the moving tractor problem.</u> (From the Pre-Instruction Quiz)

a.) Explain that the tractor is now pulling the block of concrete at a slow and steady speed.

b.) <u>Vote #4</u> Question:

How does the friction force of the ground on the concrete block compare with the friction force of the concrete block on the ground?

- $F_{G\ on\ C} > F_{C\ on\ G}$
- $F_{G\ on\ C} < F_{C\ on\ G}$
- $F_{G\ on\ C} = F_{C\ on\ G}$

14.) <u>Introduce more complex models of friction</u>

(Recommended for advanced classes)

a.) Consider an alternative model using adhesive chemical bonds. In many surface friction situations the primary mechanism consists of adhesive chemical bonds, as shown in the upper right of Figure 3.1. Reichert[3] suggests that we visualize “atomic bonds between the surfaces” modeled by thinking of “the bonds between the atoms as short pieces of elastic material connecting” an atom on one surface to an atom on another surface. When the friction force acts, these pieces of “elastic material” would tend to stretch in a diagonal fashion. Thus the qualitative properties of these forces (their direction and equality) are the same as those we have already discussed.

b.) Another mechanism causing friction comes from "plowing" of the bumps through the other surface, similar to the way in which a wire brush might leave grooves in clay when dragged across it. This is especially important when one surface is softer than another. Emphasize again that this would not change the direction of the forces or their equality.

15.) Balanced forces and Newton’s third law

Teachers wishing to make clear the distinction between the notions of balanced forces acting on one body and the equal and opposite forces of Newton’s third law may wish to discuss the diagrams below:

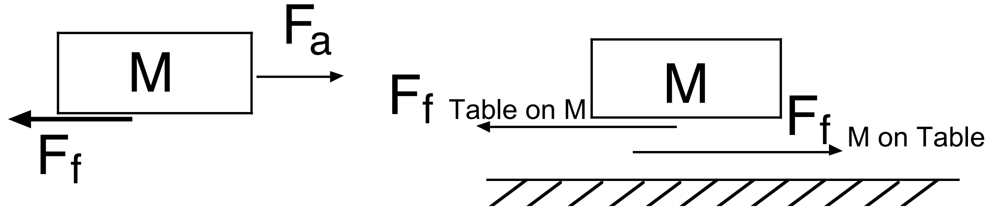

Figure 3.9

[3] Jonathan Reichert, “How did friction get so ‘smart’?,” *Phys. Teach.* **39,** 30 (Jan. 2001)

16.) Demonstrations to precede the homework

a.) Push with your finger against the end of the meter stick which pushes the book against the wall (Figure 3.10).
Emphasize the fact that the finger is pushing horizontally and not up.

b.) Ask, "Why doesn't the book fall down?"

c.) Brief discussion is optional, as this problem is on the homework.

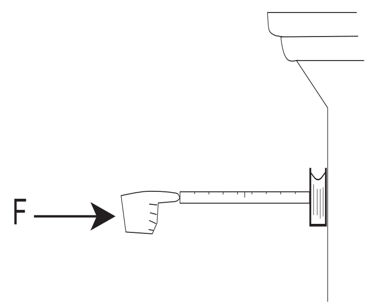

Figure 3.10

d.) Lean a log, or similar object, on a book on a wall (optional).

- Why doesn't the book fall down?

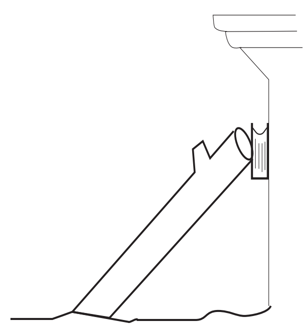

Figure 3.11

17.) Assign homework

Homework - Surface Friction - Day #1

F. TEACHING NOTES - SURFACE FRICTION - DAY #1

The teacher is reminded that the concept diagram should be drawn during the lesson as each picture is called for. This is an important aid to students as they try to make the necessary mental connections so that they can visualize how a simple model of friction works.

One hazard in this lesson is that the early part may drag if the class spends too much time on one item. It is strongly suggested that the class keep moving as the demonstrations should help pick up the pace.

The purpose of the "book on the forearm" demonstration (suggested by Arnold Arons[4]) is to have all students actually feel a force on their own bodies - the first and often best source of learning. To make the friction force more noticeable, use a book with a rough-textured or plastic cover and practice ahead of time. Moistening the forearm may also help, to increase the friction force.

Note especially the challenge question concerning the book-on-the-forearm section: "How could two forces, exerted by very different objects, possibly be equal?" The aim is to get students to question their (perhaps too ready) acceptance of Newton's third law, and thereby lead them to understand it at a deeper level. The teacher's task is to make individuals - and the class as a group - wrestle with this question rather than to supply a memorized answer. You may wish to recall the rubber bands experiment from the lessons on Normal Forces. However, we suggest that you not bring up this experiment until there has been a lot of discussion, and that after you bring it up you allow ample time for discussion of its relevance to the question at hand.

Students may be quite surprised that the force on the mass is not greater than the force on the cart from the *equal and opposite force* demonstration (Figure 3.8). They may reason (like Aristotle) that there must be an additional force on the mass to cause the motion at a constant speed. This is a deep seated belief that will only change gradually during many different experiences in a physics course.

It is quite effective to just demonstrate the meter stick holding the book against the wall at the very end of class. After students struggle with the analysis in the homework they will be ready for a discussion.

The homework problems at the end of the lesson plan emphasize qualitative understanding of friction for the static case. Several problems call for construction of a free-body diagram, which is the key to consistently being able to solve mechanics problems. You may choose to use some of these problems as the subject of classroom discussion in your next class rather than as homework. If you use them as [5]homework, be sure to leave plenty of time in the next class for discussion.

Should you choose to include the dynamic case (sections 11, 12c, and 13) in this unit, more homework with the dynamic case needs to be included.

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[4] A. Arons “A guide to introducing physics teaching”, John Wiley and Sons. (1990) p. 80

Teachers wishing to do further work with the friction concept might consider using the "bumps" model to discuss the following concepts as part of a second lesson before starting any quantitative work on friction.

a.) How does the contact area affect surface friction?

b.) How does the normal force affect friction?

c.) How is the resistive force of a medium such as air or water similar to and different from surface friction?

d.) How might smoother surfaces produce more friction?

The distinction between static and dynamic coefficients of friction may eventually help sort out the preconception about "overcoming extra inertia" when starting from a velocity of zero. In any case the teacher should realize that the foundation work done on the friction concept will ultimately help students separate the concepts of inertia, gravitational force, and friction force.

Some students will recognize that the ground is really pushing up on the bottom of the concrete blocks in a diagonal direction as shown below. We need to acknowledge to these students that physicists have made a discretionary choice (for convenience) to define the component of the force parallel to the surface as the friction force and the component of the force perpendicular to the surface as the normal force.

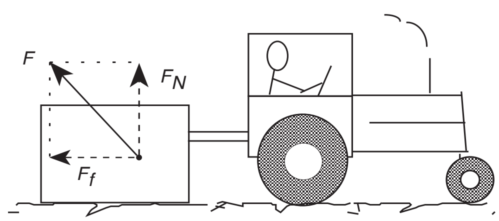

Figure 3.12

In the article referenced below, Leonard presents an interesting problem in which the solution is simplified by thinking of the diagonal force from the floor acting on the box as a single force.

William Leonard, “Dragging a Box,” *Phys. Teach.* **43,** 412 (Oct. 2001)

III. **MATERIALS FOR DUPLICATION**

A. Pre-instruction quiz

B. Homework - Surface Friction

C. Quiz and Test Questions - Surface Friction

PRE - INSTRUCTION QUIZ

Name: ____________________

Period: _____Date: __________

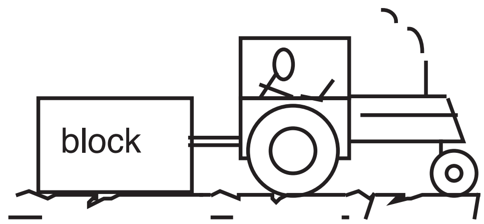

Figure 3.13

A tractor is trying to pull a very heavy block of concrete across a rough concrete floor, but is unable to move it. Draw a diagram of *just the block of concrete below* showing an arrow (vector) for *each* of the forces acting *on* the block of concrete.

(Note: Even though the tractor is pulling very hard, it is *unable* to move the heavy block).

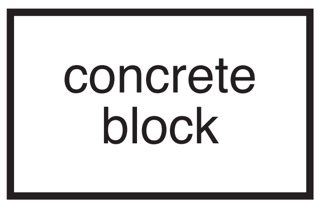

Figure 3.14

After drawing the arrows above, label each force arrow with a name for the force.

HOMEWORK - SURFACE FRICTION

Name: ____________________

Period: _____Date: __________

1.) A log is leaning on a book on a wall. Draw a separate diagram of just the book showing all of the forces acting on the book. Label each force vector clearly.

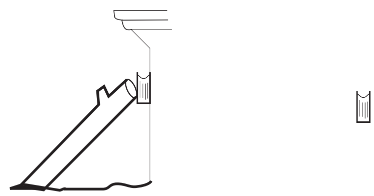

Figure 3.15

2.) A person pushes in with a finger on the end of a meter stick that pushes a book against a wall.

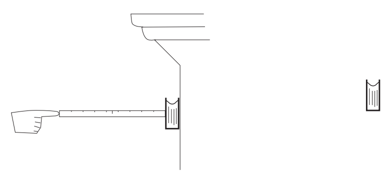

Figure 3.16

a.) Why doesn't the book fall down if the finger is pushing only horizontally? *Explain* and include a magnified microscopic view of the important surfaces.

b.) Complete the diagram of *only* the book in the figure above showing all of the forces acting on the book. Label each force vector clearly.

3.) A cement block on a glass surface has a force of five newtons applied but the block does not slide. Answer the following questions with one of the following choices:

- $F_f < 5N$
- $F_f = 5N$
- $F_f > 5N$

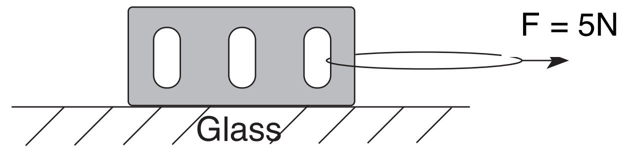

Figure 3.17

a.) How much friction force is exerted on the block? __________

b.) How much friction force is exerted on the glass? __________

c.) Suppose the cement block is moving to the right at a slow steady speed. Answer questions a & b.

4.) Consider the resistance force encountered when trying to move an object rapidly through a fluid such as air or water. How is this type of resistive force (friction) different from the friction between solid surfaces? Draw a picture of the cement block (problem 3) being dragged though the water. On what sides of the block would the water exert resistive forces?

5a.) A book is at rest on an inclined plane. Draw a separate diagram of *just the book* (as shown in Figure 3.17) showing all of the forces acting on the book.

5b.) Suppose the book begins to slide down the inclined plane at a slow steady speed. Draw a separate diagram of *just the book* showing all of the forces acting on the book.

6.) Write one sentence which states as clearly as possible what we mean when we use the words friction force in the context of solid surfaces rubbing on one another.

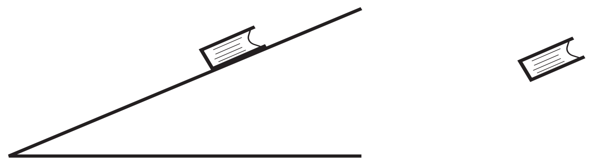

Figure 3.18

7.) Which part(s) of the concept map below are most helpful to you as you try to think about friction between solid surfaces? How does it help?

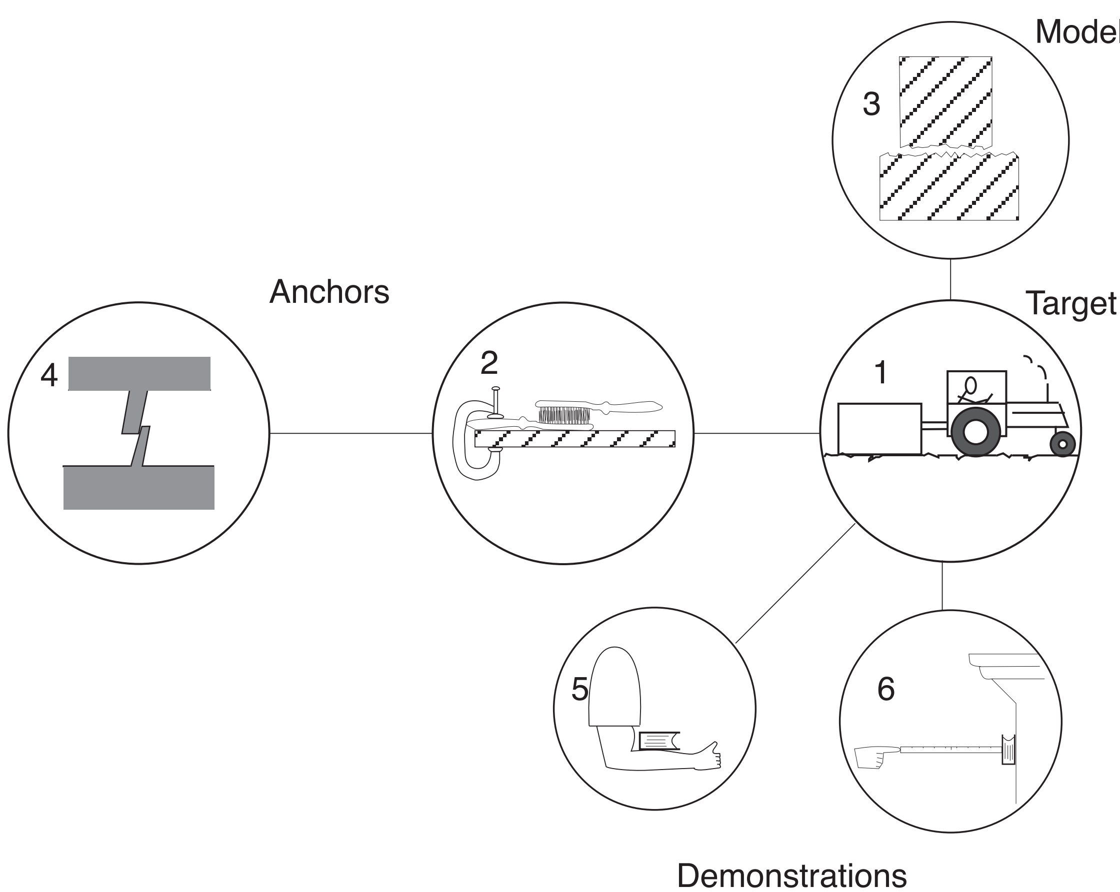

Figure 3.19

QUIZ AND TEST QUESTIONS - SURFACE FRICTION

1.) A shuffleboard puck glides across the floor, and eventually comes to a stop.

Figure 3.20

During the time the puck is moving, consider the possible forces listed below. For each of these possible forces *indicate the direction* (up, down, toward left, toward right, etc.). *If the force does not exist (or is equal to zero), write 'none.'*

Letter	Hypothetical force in situation	Direction
a.)	A force of gravity on the puck	________________
b.)	A vertical force of the floor acting on the puck	________________
c.)	A horizontal force by the floor acting on the puck	________________
d.)	A horizontal force of the puck acting on the floor	________________
e.)	A vertical force of the puck acting on the floor	________________
f.)	A force of motion that the puck has	________________

2.) Consider carefully the magnitude of the forces in the above question. If there are any forces that are equal in magnitude to other ones in the list above, show this below by identifying the equal pairs of forces (for example, does b = c).

___________ ___________ ___________ ___________

3.) A shuffleboard puck glides across the floor, and comes to a stop. Draw a free body diagram of the puck while it is still sliding (it has left the player's stick but has not yet come to a stop). Be careful to include all the forces you think are acting on the puck. Be sure to label each arrow (force vector) with the name of the force and the body that exerts the force.

4.) Joe pulls on a string which is attached to a box (A). Box A is on top of box B. Box B does not slide across the floor, and box A does not slide across box B.

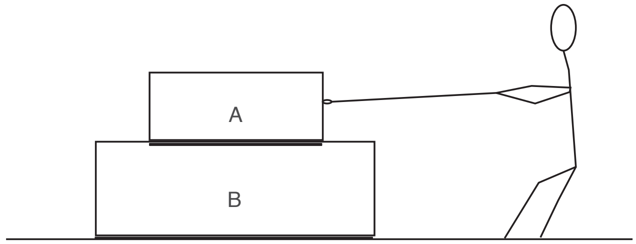

Figure 3.21

a.) Identify and draw arrows for all the horizontal forces and all the vertical forces acting on A and those acting on B. Label each force, and state its source (state what body exerts the force.)

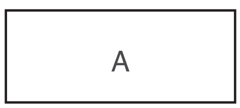

Figure 3.22

Figure 3.23

b.) If there are any forces that are equal in magnitude to other forces in your diagrams, indicate these equalities in the spaces below.

c.) Suppose block A now slides across block B with a slow steady speed. Identify and draw arrows for all the horizontal forces and all the vertical forces acting on A and those acting on B. Label each force, and state its source (state what body exerts the force.)

5.) A spring scale is attached to the spine of a book. A man pulls on the other end of the spring scale. The spring stretches, and exerts a pull on the book to the left. However, *the book remains at rest* on the table.

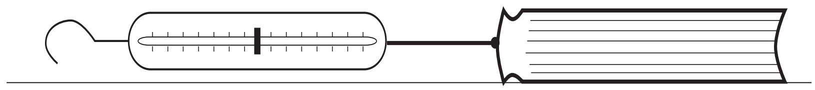

Figure 3.24

a.) What force or forces act(s) up or down on the book?

b.) What force or forces act(s) sideways on the book?

c.) Draw a "free body" diagram showing all the forces acting on the book.

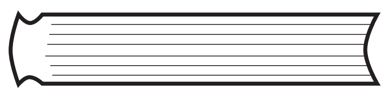

Figure 3.25

d.) Describe any relations that exist between the sizes of some of the forces acting on the book. (For example, are there two forces that are equal in magnitude to each other or are there some that you are sure are larger than others?)

6.) The car shown is traveling at a high speed but the driver has her foot on the brakes so she is slowing down. The brakes are making the car slow down rapidly but the car is not skidding.

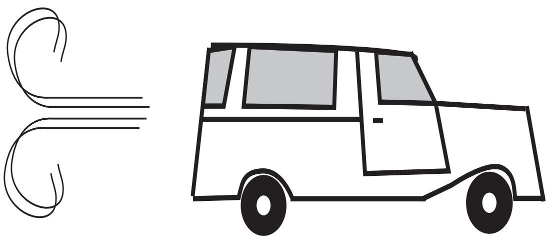

Figure 3.26

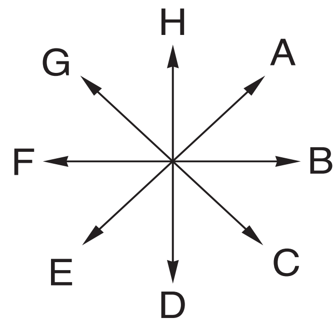

Figure 3.27

a.) What is the direction of the frictional force caused by the road acting on the wheels? ________________________

b.) What is the direction of the frictional force caused by the wheels acting on the road?________________________

7.) The car in the figure above is *accelerating* to the right because the driver has the gas pedal pushed to the floor. The car is accelerating rapidly but the wheels are not skidding.

a.) What is the direction of the frictional force caused by the road acting on the wheels? ________________________

b.) What is the direction of the frictional force caused by the wheels acting on the road? ________________________

8.) A person pushes with a finger on the end of a meter stick that is holding a book against the wall. Draw a proper free body diagram of the book. In other words draw a diagram (of only the book) showing all the forces acting on the book and label each force clearly.

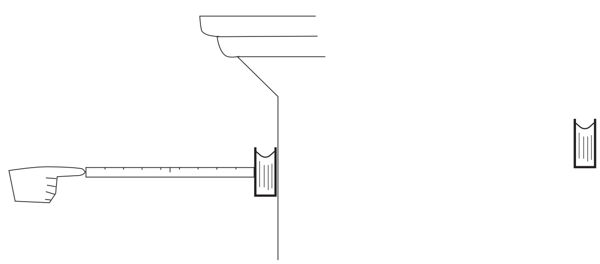

Figure 3.28

9.) A box is pulled with a constant force F_a as shown on a rough horizontal surface by a rope which makes an angle of 25 degrees with the horizontal. The block does not slide.

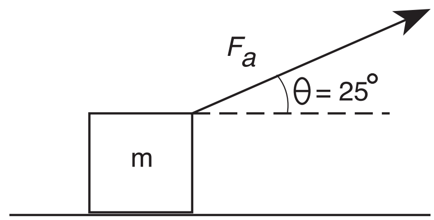

Figure 3.29

a.) Draw a correct free body diagram for the block including proper labels on each force.

b.) Write a correct expression for the sum of the force components acting in the x direction.

c.) Write a correct expression for the sum of the force components acting in the y direction.

10.) Two students are working together to move a heavy box that does not move. What is the reason?

Figure 3.30

a.) The force of friction equals the sum of their forces.

b.) The force of friction is greater than the sum of their forces.

c.) The force of gravity is greater than the friction force.

d.) The friction force is greater than the gravity force.

e.) The force of friction is greater than or equal to the sum of their forces.

UNIT 4

Tension Forces

UNIT #4 – TENSION FORCES

I. OVERVIEW OF THE TENSION FORCES UNIT

A. MAJOR PRECONCEPTIONS POSING DIFFICULTIES IN THIS UNIT

1.) The tension in a rope is the sum of the magnitudes of the forces acting on the two ends of the rope.

2.) Strong ropes pull with more force than weak or stretchable ropes.

3.) A spring scale is not symmetrical, and thus does not pull equally on both ends.

4.) Walls or posts that are rigid do not exert a force on a rope tied to them.

5.) Two ropes can pull with unequal forces on each side of a static, frictionless object.

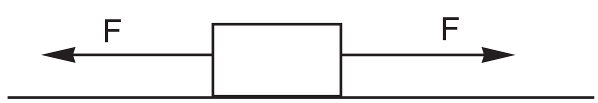

Figure 4.1

6.) One spring stretches more when it acts alone compared to when it is in series with another spring under the same forces.

B. GENERAL STRATEGY OF THIS UNIT

The design of this unit assumes some earlier work with springs. The earlier units on *Normal Forces* and *Friction Forces* and a lab experience working with springs are recommended.[1]

[1] If one is planning to cover friction later, homework problems 5 and 7 should be omitted.

The concept diagram in Figure 4.2 covers two days of class and is the best way for students and teachers to keep many concepts visible at one time.

The target problem with Superman is usually controversial enough to start a good discussion. The lesson then moves to the anchor situation followed by a series of bridges, spring models and demonstrations as shown in the concept diagram. The teacher is encouraged to withhold the physicist's view as long as possible while also delaying and sensing the right moment for demonstrations which may go unappreciated if conducted before most students are asking the right questions. Since the range of super heroes is always changing, the teacher may wish to ask for a class suggestion other than Superman.

Pulleys are introduced to show that the tension is the same throughout a rope even if it goes over a pulley. Eventually it becomes appropriate to present the distinction between tension and force which are combined in the temporary "tension force" term through most of these two lessons.

While these two lessons are designed for typical classes of approxiamtely 45 minute teaching blocks, most of these two lessons could be dealt with in a single long-block class. A discussion of homework problems on an additional day would be valuable.

C. **CONCEPT DIAGRAM**

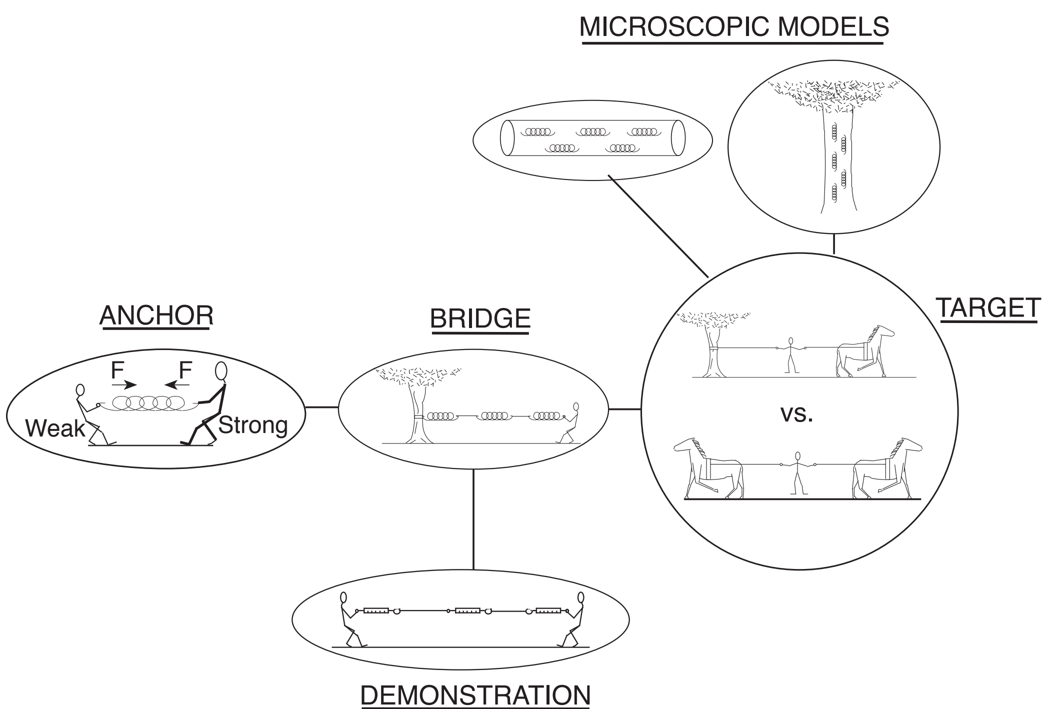

Figure 4.2

D. THE PHYSICIST'S VIEW

One major reason for working with this unit is to help students gain practice with Newton's Third Law in cases where objects are pulling on each other. To the physicist much of this lesson is a conceptual revisitation of the lessons on *Normal Forces* considered earlier. However, the concept of "tension" introduces new sources of confusion that trouble many students who are still learning to articulate their ideas about the nature of force.

Through these lessons students gain practice in articulating what static forces are doing. They need to learn to be specific about which object is pulling on which other object. Throughout the struggle many students will be helped by imagining springs substituted for pieces of rope so that they will be able to visualize the need for two forces to act on each spring in order for it to stretch (be in tension).

The importance of the spring scale as a device for measuring force cannot be overestimated. Some students may need to be confronted with the fact that a spring scale only contains a spring. Others may need to be asked about how much force must act on *each* end of the scale if the pointer is on the 10 N mark.

After the fundamental issues about the nature of force have been encountered in these lessons many students will be ready to distinguish between "force acting on one end of a rope" and the "tension in a rope". The forces acting <u>on</u> the ends of the rope and the forces exerted <u>by</u> the ends of the rope can all be represented by force vectors. The tension in the rope is determined by the magnitude of one of the two equal and opposite forces acting on an element within the rope. Since these two forces point in different directions it may be helpful to think of the "tension in a rope" as a scalar quantity.

II. TENSION FORCES – LESSON 1

A. OVERVIEW OF THE LESSON

This lesson builds from an anchor situation with a spring under tension to help students construct a mental model for use in problems with ropes under tension. The target problem (Vote #1) inserts a person in the middle of the rope to help the student visualize the two-way nature of the equal forces acting on any element of the rope.

The early demonstration in the lesson is only provided for motivation and to help students focus on the tension concept. No measurements should be taken early in the lesson as one would like the students to struggle with their mental models rather than just try to memorize the correct answer. Hopefully, class discussion can elicit from the students most of the bridging ideas and even the microscopic model suggested in the lesson. With occasional challenges or the use of "devil's advocacy", the teacher can withhold his/her position until it is time for the demonstrations, with measurements, near the end of the lesson.

It is recommended that the teacher draw the concept diagram on the board as the class progresses to help students review the mental models.

These two lessons were designed for use in relatively short classes of approximately 45 minutes. Teachers with longer classes could cover much of this material in a single long-block class.

B. MATERIALS

1.) 2 six foot pieces of rope or cord

2.) 3 spring scales (preferably transparent)

3.) 3 "S" hooks (for quick rope connections)

4.) voting sheets

5.) Homework - Tension Force - Day #1 sheets

C. OBJECTIVES

1.) The student should be able to visualize the similarities between ropes and springs.

2.) The student should understand that the tension force is the same throughout a piece of rope that is under tension.

3.) The student should be able to create a mental model of the forces acting on a single element of a rope or a spring that is under tension.

D. LESSON PLAN - TENSION FORCES - DAY #1

1.) Class introduction

Today we are going to investigate the idea called "tension force". This idea of "tension force" is very useful in situations where we wish to pull on something with a rope or a piece of wire.

2.) Focusing demonstration

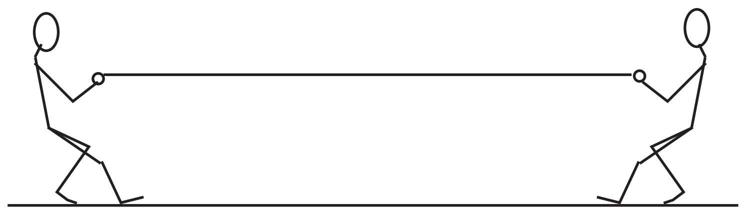

Figure 4.3

Have a pair of students pull on the two ends of a rope as hard as they can without producing any motion (Figure 4.3). You should be able to "twang" the rope a bit and comment that there seems to be a "big tension force" in the rope and *we are seeking to more clearly understand the meaning of this kind of force*. (This is to be a brief focusing demonstration with little discussion.)

3.) Introduce the target problem

a.) Introduce the target problem in the slightly obscure and comical form that follows as Vote #1. Draw the two diagrams on the board as you tell the story.

b.) Set the scene:

Some invaders from another galaxy have captured Superman[2] and wish to pull him apart to examine his insides. They have also found two identical horses and they are arguing about the most effective way to pull him apart. Some invaders propose tying one horse to each arm and pulling, while others suggest tying one rope to a big tree and pulling with only one horse.

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[2] Other possible super heroes may be considered.

c.) Vote #1 question

Which situation would cause Superman the most discomfort due to the largest tension force?
Remind the class that it is important to include the makes sense score with each vote.

- Using two horses

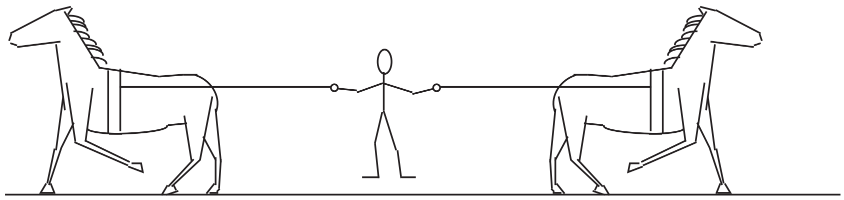

Figure 4.4

- Using one horse and one tree

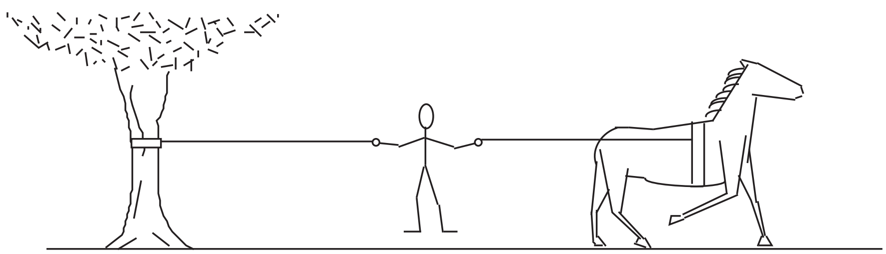

Figure 4.5

d.) Discussion of responses to Vote #1

The teacher should remain neutral at this stage of the discussion and ask volunteers to defend both answers.
Some students may ask to vote for the "equal option" in the choices offerered. It is suggested that the teacher should indicate in a low-key fashion, that it is OK to write "equal" in the voting space. The teacher might add the comment, "These two situations look very different to me."

4.) Introduce the anchor situation

a.) Draw Figure 4.6 and explain the situation.

A large person and a small person are pulling hard on a spring. The smaller person tries harder, but the larger person is stronger. The spring stretches out and then remains still.

If an appropriate spring is available, this could be demonstrated with a large and small student.

b.) A public vote on this question is probably adequate.

Which force is larger, the force of the spring on the large person or the force of the spring on the small person?[3]

- $F_{\text{spring on L}} > F_{\text{spring on S}}$
- $F_{\text{spring on L}} < F_{\text{spring on S}}$
- $F_{\text{spring on L}} = F_{\text{spring on S}}$

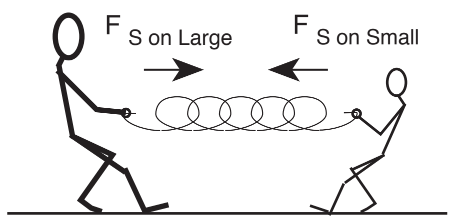

Figure 4.6

c.) Note on the public vote

If less than 90% of the class is correct on the public vote, ask how the spring could pull on one end harder than on the other end when the spring is symmetrical.

[3] It is important to ask about the forces of the spring acting on the people. This is done so the symmetrical nature of the spring may be utilized in the argument.

5.) Present a bridging example

a.) Draw and explain Figure 4.7.

The large and the small person are both pulling on springs connected by a rope, and *there is no motion*.

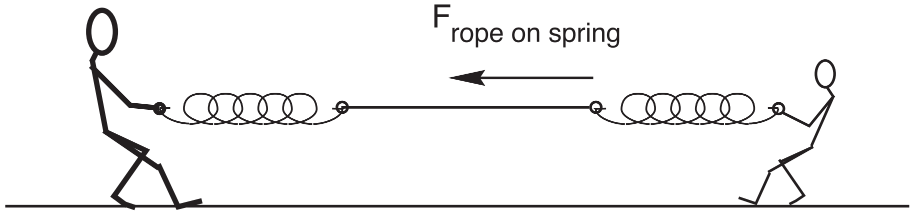

Figure 4.7

b.) Vote #2 question

If each person pulls with a force of 100 N, what is the force of the rope pulling on the right spring?

- $F_{\text{R on S}} > 100$ N
- $F_{\text{R on S}} = 100$ N
- $F_{\text{R on S}} < 100$ N
- $F_{\text{R on S}} = 0$ N

c.) Discussion of responses to Vote #2

While the teacher is urged to remain neutral at this early stage of the lesson, it should be possible to draw comments from the class indicating that the spring should feel equal forces on both ends or it would not remain stationary.

After some discussion ask the class if they can see a similarity between this problem and the Superman problem (target).

6.) Demonstration (optional) The teacher may wish to omit this demostration in more advanced classes.

If there appears to be uncertainty among students at this stage in the lesson, the following demonstration may help solidify student confidence in the result of the two spring discussion. We suggest a big and a small student with 2 spring scales connected by a rope (or a long coil spring) as in Figure 4.8.

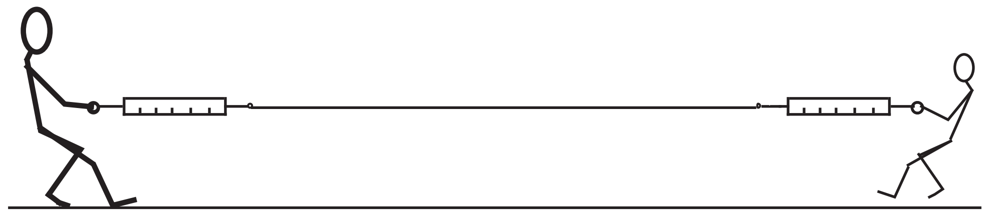

Figure 4.8

7.) Bridging to add a spring in the rope

a.) Refer to the original Superman diagram on the board, and then ask if anyone has suggestions about how placement of more springs in the rope will help us think about the Superman problem. *Draw the diagram shown in Figure 4.9 without numbers*.

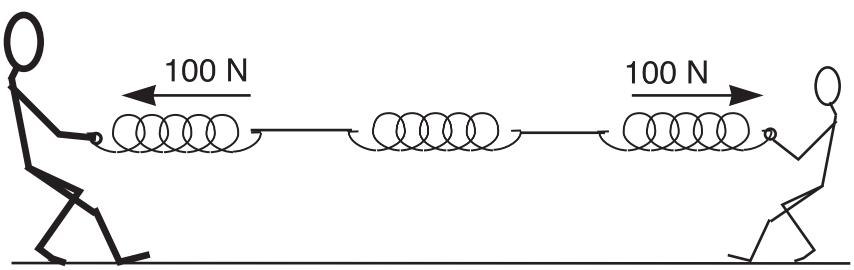

Figure 4.9

Try to elicit from the class discussion the idea that the role of the middle spring is similar to that of Superman in the target problem. If necessary, ask “can we think of Superman as a spring?”

8.) Bridging example (Vote #3)

a.) Add the 100 N labels to the outside springs in the diagram (Figure 4.9).

b.) Vote #3 question:

"What size force does *each end* of the middle spring experience?"

c.) Record the number of newtons on your answer sheet along with your makes sense score.

d.) Discussion: If the 100 N answer seems to be accepted with no struggle, challenge the class with "*How could the middle spring possibly feel a force of only 100 N if 100 N acts on each end*?"[4]

Consider the middle spring in the 3 spring problem. How much force does each side of the middle coil of the middle spring feel? Draw Figure 4.10 to help them think about what the middle coil of the spring experiences.

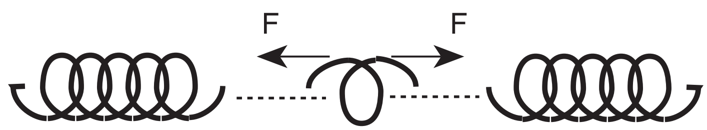

Figure 4.10

9.) Discussion of the microscopic rope model [5]

a.) While the teacher may no longer be able to remain neutral, it will probably be helpful to introduce the following ideas:

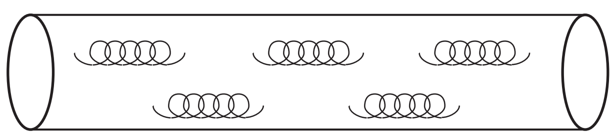

Figure 4.11

- The rope may be thought of as made of many microscopic springs (see Figure 4.11).
- Each coil of a spring may be viewed as a separate piece which feels equal forces on both ends (see Figure 4.10).
- Perhaps pass around a variety of rope samples.

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[4] This wording is suggested to force students to clarify what is happening here.
[5] Although it is tempting for the teacher to demonstrate the result with three spring scales at this point, we urge patience as the demonstration is included in the next lesson.

10.) Vote #4 - Repeat the original Vote #1 "Superman question" and emphasize the importance of the makes sense score. If more time is available, this vote may be omitted and the session may move along with Day #2 Lesson.

11.) Assign homework

Homework - Tension Forces - Day #1

E. **TEACHING NOTES - TENSION FORCES- DAY #1**

A few students may be offended by the violence related to Superman in the target problem situation. It is suggested that you assure them no harm ever comes to Superman, or the alternate super hero you choose.

Some difficulty may be avoided by drawing the Superman diagrams so Superman's feet are *not touching the ground*. Some students think Superman somehow compensates with his feet if they touch the ground.

It is recommended that only two answers be offered by the teacher when the target problem (Superman) is introduced. Students at times pick the equal choice too quickly, so the intent here is to gently encourage them to make such a choice after some personal struggle.

The question of whether tension is the same everywhere in a lightweight (massless) rope frequently arises during the discussion of the three springs case (Figure 4.9). Draw out or present the argument that the rope can be thought of as a chain of springs, and that if the springs were stretched more in one half of the rope, that it would stretch the other half more until the tension was equal. Therefore, in a rope whose mass is insignificant, the tension is the same everywhere in the rope.

After Vote #3 the discussion of the center spring and finally the center coil in the center spring should be done with great care. The diagram (Figure 4.10) that carefully isolates the center coil in the spring and finally the microscopic model (Figure 4.11) of a rope, are both important foundation ideas for the next day's lesson.

III. TENSION FORCES – LESSON 2

A. OVERVIEW OF THE LESSON

This lesson introduces more of the bridging examples shown in the original concept diagram Figure 4.2. The first example uses a big tree to represent the notion of a rigid object as an agent exerting force on one end of a rope. It may help some students here to refer back to some of the examples from the unit on Normal Forces.

The lesson then moves on to consider how a system of ropes and springs adjusts when the force is increased on one end of the system. The final bridging example carefully replaces a horse with a tree to lead the discussion back to the original question at the start of Day #1. There will be times when class discussion may lead the teacher to change the order in which these three examples are presented, but each example seems to help a significant number of students.

The demonstrations with ropes and springs are each important to some students. If you felt you needed to introduce some of these demonstrations earlier fill in with the rest before the end of the lesson.

After the formal definition of "tension force" is presented the pulley demonstration is necessary. If you run short of time, you may wish to postpone the microscopic model discussion or the formal tension definition work until the next day in order to include the pulley demonstrations. Notice the Day #2 homework requires extensive use of pulleys.

B. MATERIALS

1.) 2 six foot pieces of rope

2.) three spring scales (transparent)

3.) 1 rubber rope (bungy cord)

4.) three "S" hooks (for easy connections)

5.) pulley demonstration set up (see Figure 4.20)

C OBJECTIVES

1.) The student should be able to define the concept of tension in a rope using words and diagrams.

2.) The student should understand that a spring scale is simply a symmetrical spring that is inside a fancy container.

3.) The student should understand that a pulley is a device that changes the direction but not the magnitude of a force caused by tension in a rope.

D. LESSON PLAN - TENSION FORCES - DAY #2

1.) Review homework - Day #1

The concept diagram parts from Day #1 should still be on the chalk board, on a homework sheet, or transparency.

2.) Bridge to include a rigid object (Vote #1)[6]

a.) Draw the bridging case below with a tree.

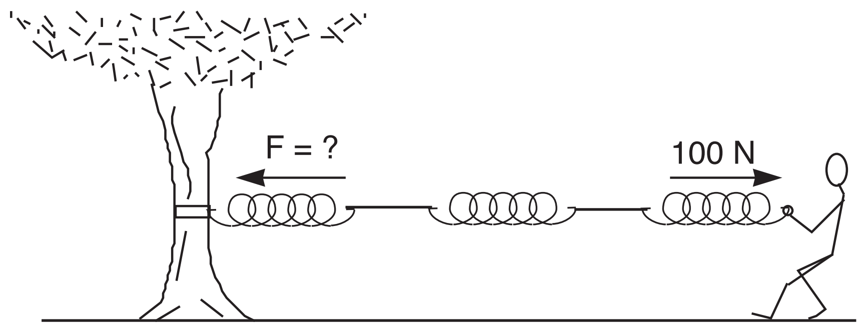

Figure 4.12

b.) Vote #1 - The rigid object question

If the man pulls on the right spring with a force of 100 N, how much force does the tree exert on the left spring?

- $F_{T \text{ on spring}} < 100$ N
- $F_{T \text{ on spring}} > 100$ N
- $F_{T \text{ on spring}} = 100$ N

c.) Discussion

Encourage students to defend their positions. Ask how the diagrams with three springs compare to the target problem (Superman). Focus students on the middle spring in each situation. [7]

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[6] For variety, another voting style such as "pair voting" might be appropriate during this lesson.

[7] Many students will have difficulty with the idea that a strong, rigid tree is able to adjust and pull with 100 N. While we encourage teachers to allow some time to struggle with this issue the teacher should eventually acknowledge that both forces equal 100 N. The next 3 sections of the lesson serve as bridges to help students accept this equality.

3.) <u>System adjusts to changing forces</u>

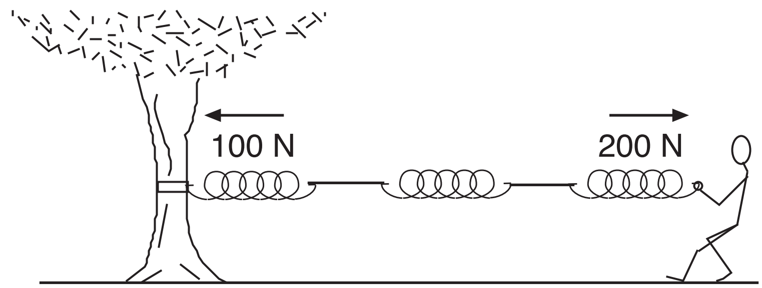


Figure 4.13

a.) If the class has not raised the issue of changing forces, ask the following question and *modify the diagram* (change 100 N to 200 N).

b.) Question:

If the person pulls harder (increases to 200 N), how can the force exerted by the left spring change?

c.) Discussion of changing forces

During the discussion, try to help students clarify the ideas that:

- The rope stretches a little.
- The springs all stretch out the same amount.
- The rigid tree even bends a little.
- The "tension force" becomes 200 N throughout the system. (The teacher needs to move down the line through the whole system and *write in 200 N force vectors pointing both ways at each interface as shown below).*

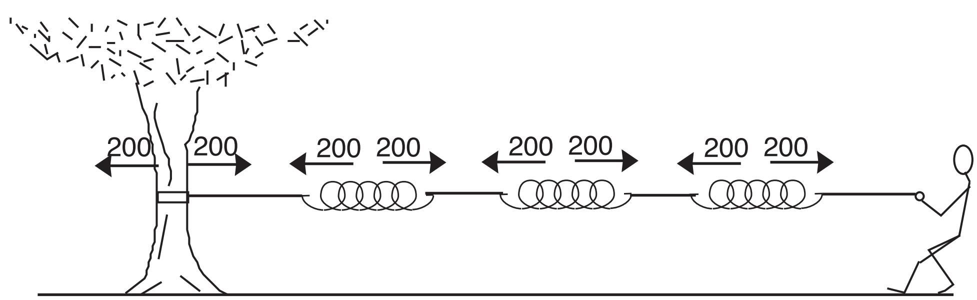


Figure 4.14

4.) Bridge - replacing a horse with a tree

a.) The final bridge is offered for students who still find it hard to believe that one horse can cause the same tension force as two horses.

b.) Draw Figure 4.15 and explain that you wish to start with the two horses pulling on Superman, then clamp (attach) one rope to a very strong tree while the horses are still pulling. The right horse may now be removed.

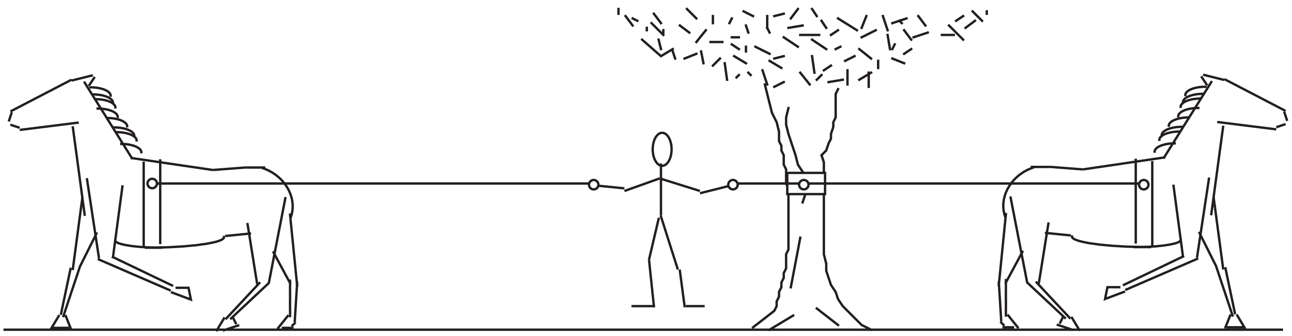


Figure 4.15

c.) Discussion

Ask students how this situation is similar to and how it is different from the original Superman problem.

If students introduce comments about ropes and trees being made of springs like tables and fire hydrants, it will lead into the molecular model in the next section.

5.) Vote #2 Repeat the original target vote with Superman. Once again, it is important to remind students that you care about the makes sense score.

.

6.) Review the microscopic model

a.) If students have not introduced the microscopic springs during earlier discussions, the teacher should review the idea that “rope atoms and tree atoms may be thought of as connected by spring-like bonds.” Thus, we may think of a tree as containing many little springs, or a tree trunk might be thought of as one large strong spring.

b.) Add these diagrams (Figure 4.16) to the concept diagram on the board.

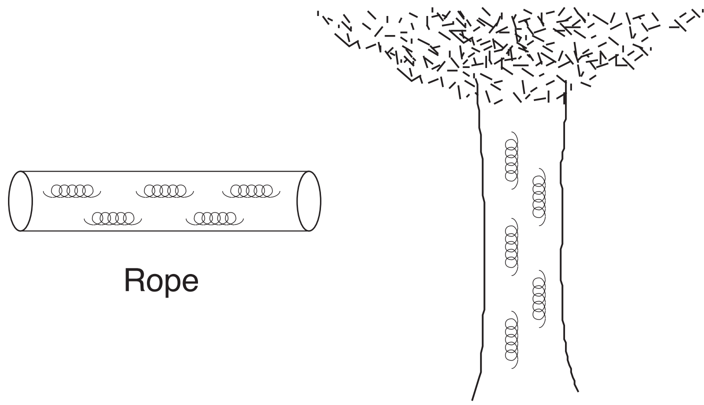


Figure 4.16

7.) Vote #3 The middle scale

a.) Draw Figure 4.17 (below) on the chalkboard.

b.) Vote #3 Question

"What will the middle scale read if the end scales each read 2.5 Newtons?" Emphasize the importance of the makes sense score on this vote.

8.) Demonstrations

a.) Using the spring scales, rope segments with loops for quick connections, "S" hooks, and rubber rope (bungy cord), try the following setups and any others students suggest. Be sure to ask the class for predictions just before critical readings are taken.

After readings are taken in Figure 4.17 below, have the student on the right hook the scale to a rigid object attached to a wall, keeping the rope under steady tension, Figure 4.18.

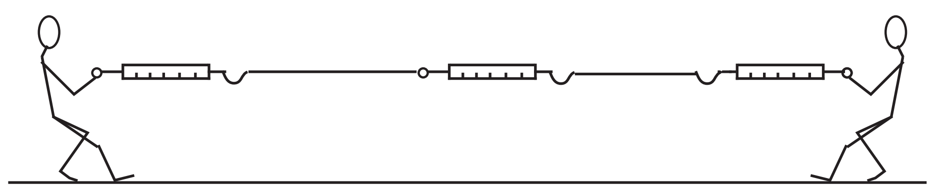


Figure 4.17

b.) After the initial readings in Figure 4.18, ask the person on the left to pull with twice as much force. Once again, take all three readings.

If some students need the challenge ask, "How does the wall 'know' to pull twice as hard?"

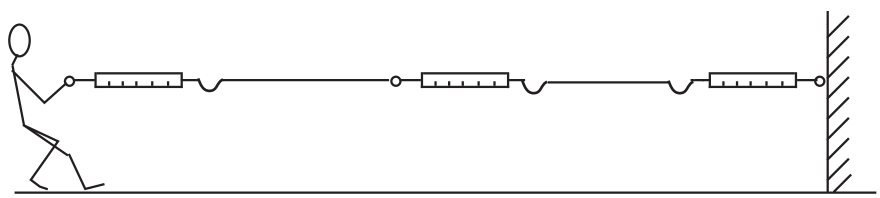


Figure 4.18

In Figure 4.19 replace one of the ropes with a piece of rubber rope or bungy cord and again check the three scale readings. Try to be open to special student requests such as turning a scale around or placing two spring scales in the center facing each other.

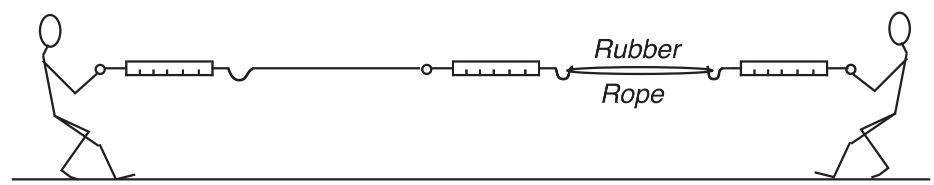


Figure 4.19

9.) <u>Vote #4 - The target problem again.</u> The teacher may choose to omit this vote in more advanced classes.

Repeat the original target question, about Superman, emphasizing the importance of the makes sense score.

10.) <u>Present the definition of tension</u>

Tension is the magnitude of the force on *one end of an element* within the rope. That is, tension is the reading one would get when placing a spring scale anywhere in the rope. Tension is a cause of stretching (and sometimes breakage) in ropes and parts of buildings.[8]

[8] See **<u>THE PHYSICIST'S VIEW</u>** regarding force as a vector and tension as a scalar.

11.) Introduction of pulleys

a.) A pulley is a special device (usually assumed to be free of friction) which allows us to change the direction of a rope without changing the tension in the rope.

12.) Demonstrations showing that pulleys do not change tension[9]

a.) Use the pulley arrangement shown in Figure 4.20.

b.) Instruct one student to remain stationary holding one scale and then have the second student pull with a different force at each of the three angles shown. Compare the scale readings on each case and show that they are equal.

c.) Emphasize the fact that the tension (a scalar, not a vector) is equal in these situations for we do not need to be concerned with the direction of the force.

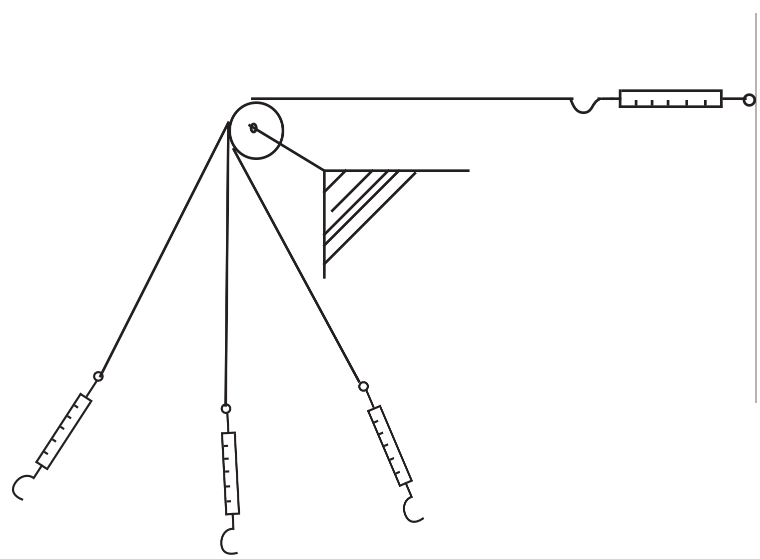


Figure 4.20

12.) Assign homework

Homework - Tension - Day #2

[9] As an alternative to this demostration, students could perform this as a investigation in small groups at their lab stations. The teacher is advised to check to be sure all scales are zeroed, and to make certain small frictional effects are considered.

E. TEACHING NOTES – TENSION FORCES – DAY #2

You may wish to avoid the use of individual voting sheets on Day #2 by using only public votes or pair votes. Votes #2 and #3 are repeats so you may only wish to tally the makes sense scores for these votes. Teachers are reminded that the voting process is not only important to provide feedback for the teacher about the student's conceptual progress, but is also a significant aid in keeping students focused and invested during the discussions.

Frequently students worry about whether it is the horse or the rope that is exerting a force on Superman in the target problem (some students will say that it is really the horse). Point out that in physics, we consider as forces on A only those forces acting immediately on A from an entity B that is interacting directly with A. We then speak of chains of force causing forces such as D pulling on C pulling on B pulling on A. The following diagram may help. Which force is acting *on* Superman?

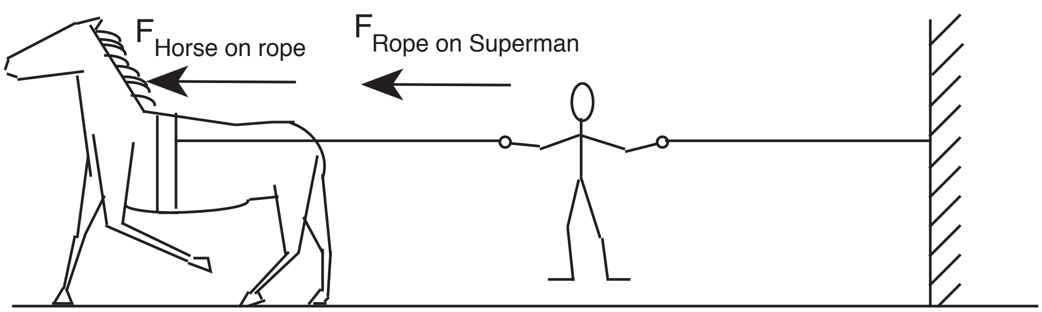


Figure 4.21

As in earlier lessons, it is recommended that the teacher draw the concept diagram on the board as the class progresses to help students review the mental models. If some students introduce bridges in a slightly different order draw in the diagrams as they are offered for discussion.

The use of the term "tension force" is suggested through out this lesson to help students solidify the connection between the word tension and the force concept. At the end of the second day's lesson the formal distinction should be presented, but the early emphasis in these lessons is placed on connecting the ideas of force and tension as well as developing strong intuition around situations in which forces act to elongate objects.

For conceptual level physics classes we especially recommend Hewitt's lab experiment dealing with pulleys and tension.[10] The reinforcement from the lab should be a valuable follow up to this lesson.

Some teachers may prefer to show the masses instead of the weights of the object in Day #1 Homework problems 6 and 7.

---

[10] Robinson, Paul. Conceptual Physics. Laboratory Manual. San Francisco: Addison-Wesley, 2002.

Many editions have an experiment entited "Tug of War."

IV. **MATERIALS FOR DUPLICATION**

A. Homework Problems

1.) Tension - Day #1

2.) Tension - Day #2

B. Quiz and Test Questions - Tension

HOMEWORK - TENSION FORCES - DAY #1

Name: ____________________

Period: _____Date: __________

1.) The student pulls on the spring scale with a force of 50 N. How would you expect the results to be different if the spring scale were turned around? Why?

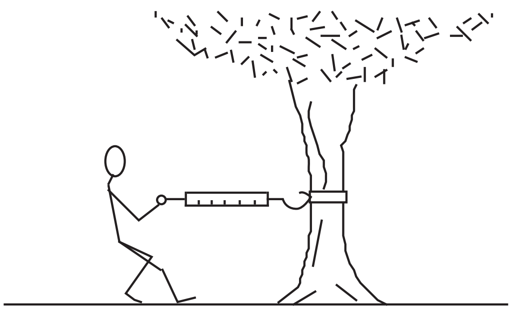


Figure 4.22

____

____

____

____

____

2.) Since a spring scale contains just a spring, why is there a small error introduced when you use a spring scale upside down to measure a force?

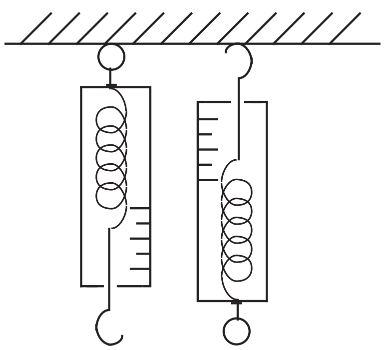


Figure 4.23

____

____

____

____

____

3.) A car is pulling on a cart with a stretched rubber rope, but the cart does not move because it is connected to another car with a strong rope. How would you explain to a skeptic that *both cars* feel equal forces?

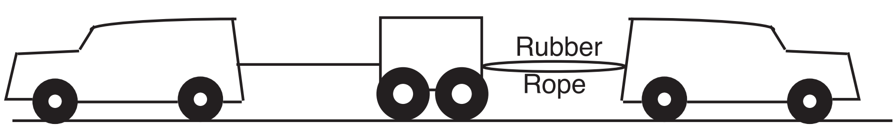


Figure 4.24

4.) Three identical springs are connected to a wall on the right and a block on the left. A person pulls on the rope so the scale reading is 450 N.

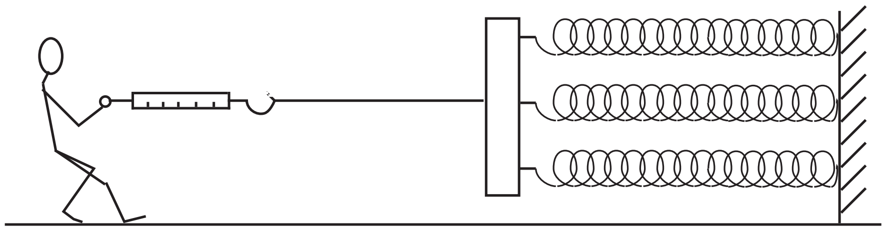


Figure 4.25

a.) How much force is exerted on the wall by one of the springs? __________

b.) How much force does the rope exert on the wooden block? __________

5.)

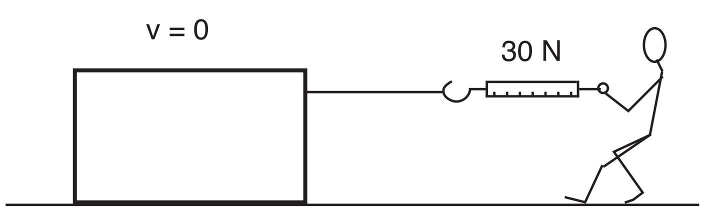


Figure 4.26

The person above is pulling on the large block but it doesn't move.

a.) Determine the size and direction of the friction force acting on the block.

____

b.) Determine the force of the rope pulling on the block. __________

c.) Determine the "tension force" in the rope. __________

6.) The person is pulling up on the spring scale, but the box remains on the table. Find each of the following:

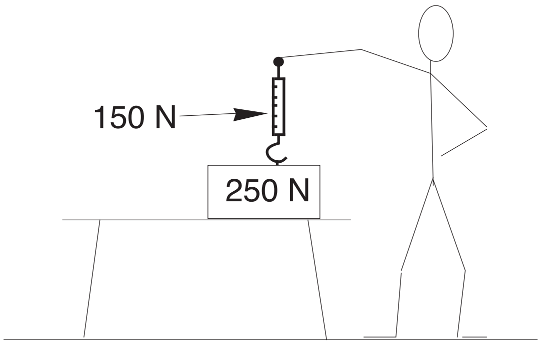


Figure 4.27

a.) Force of the table on the box. ___________

b.) Force of the box on the table. ___________

c.) Force of gravity acting on the box. ___________

d.) Force of the hand on the spring scale. ___________

e.) Force of the box on the spring scale. ___________

7.) Two people are pulling on a large block, weighing 300 Newtons, that does not move.

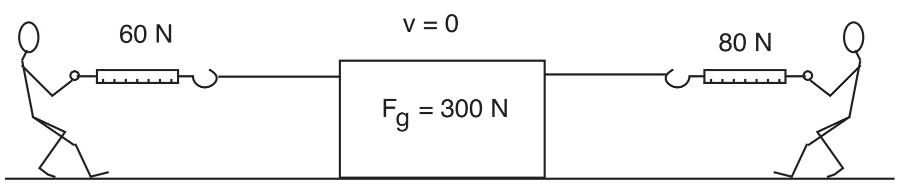


Figure 4.28

a.) Find the direction and size of the friction force from the floor acting on the block. ___________

b.) What is the "tension force" in the left rope? ___________

c.) What is the "tension force" in the right rope? ___________

HOMEWORK - TENSION FORCES - DAY #2

Name: ____________________

Period: _____Date: __________

1.)

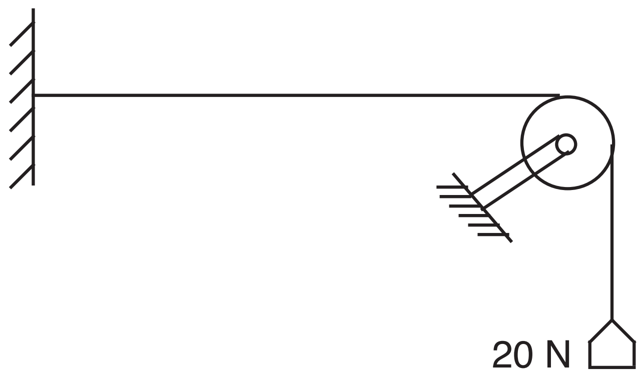


Figure 4.29

a.) Determine the force of the rope pulling on the wall.

____

b.) What is the tension in the horizontal part of the rope?

____

c.) What is the tension in the vertical part of the rope?

____

d.) What assumptions must we make about the pulley in this type of problem?

____

2.) Does it make sense to you that Superman would feel the same thing in both the situation with two horses and the situation with one horse and a tree? How do you make sense of this situation? If not, what troubles you most?

3.) A car is pulling on a cart with a stretched rubber rope, but the cart does not move because it is connected to a strong wall with a strong rope. How would you explain to a skeptic that the tension force in the rubber rope is equal to the tension force in the strong rope?

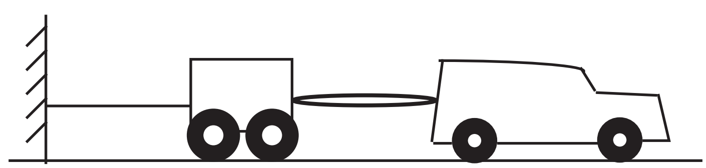


Figure 4.30

4.) A student sits on a swing with the two ropes joined as they pass over a pulley that hangs from the ceiling.

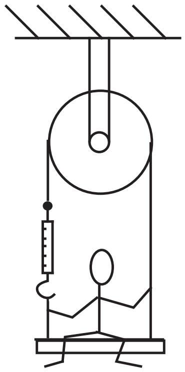


Figure 4.31

a.) If the student weighs 820 N, what would you expect the scale to read?

____

b.) What assumptions did you make in part a.)?

5.) The student from the previous problem now sits on another swing over the pulley shown below. The spring scale is attached to a massive cement block that will not move.

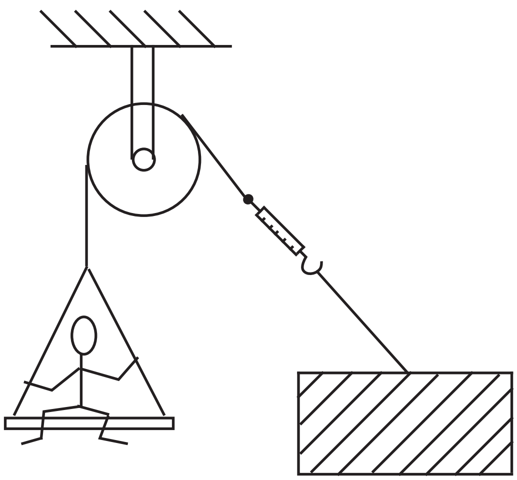


Figure 4.32

a.) What will the scale read in this situation?

____

6.) Explain how you would use an instrument to measure the force acting on one end of a rope.

7.) Consider the "tension force" acting in each of the three springs if the spring scale reads 60 N in the figure below.

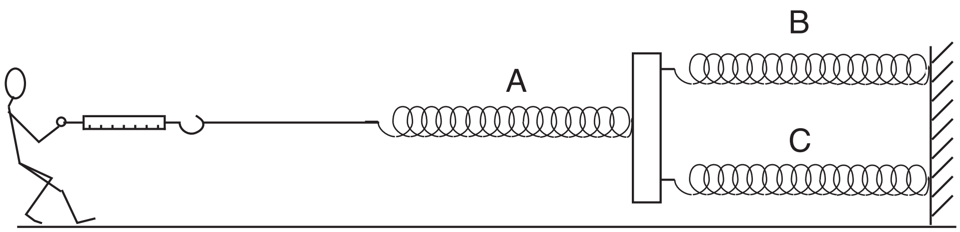


Figure 4.33

a.) Determine the tension in each of the springs.

Spring A __________; Spring B__________; Spring C __________

b.) Find the force exerted by the person on the scale. __________

8.) Explain how one could use a measuring device to measure the tension in the middle of a rope.

If two people pull on a spring scale that remains stationary, what is the meaning of the force reading shown on the scale? Which person does it apply to?

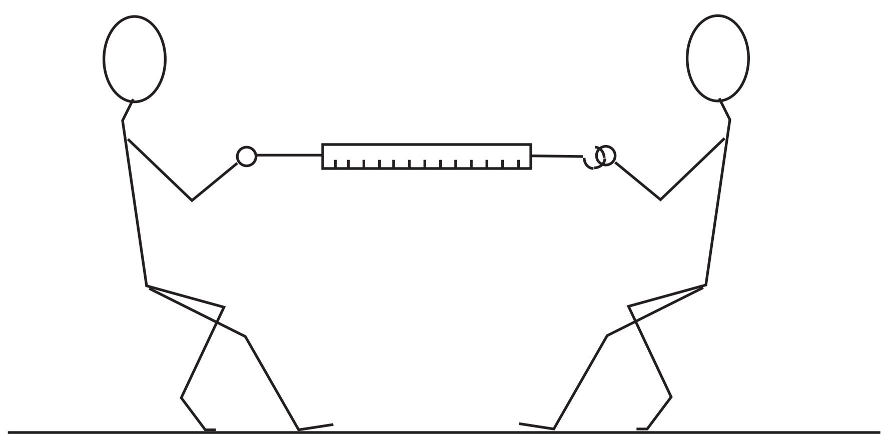


Figure 4.34

10.) In the set up on the right it is quite easy to talk about the force acting on either end of a rope or the tension somewhere in the rope. Use this example to explain clearly the difference between "force" and "tension".

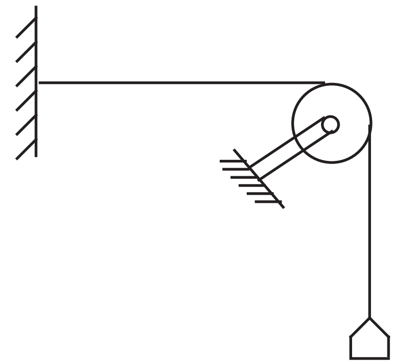


Figure 4.35

QUIZ AND TEST QUESTIONS - TENSION

1.) Each of the construction workers pictured below weighs 900 N. What would the spring scales read in each of the following situations? Give explanations for each of your answers.

Assume:

- In each case nothing is moving.
- The large pulleys have frictionless bearings.
- The boards the workers sit on, the ropes and the scales have negligible mass.

a.) spring scale (Figure 4.36) reading: ______
explanation:

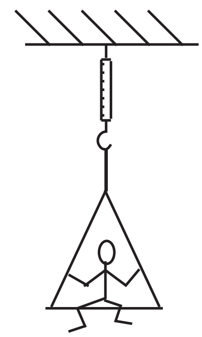


Figure 4.36

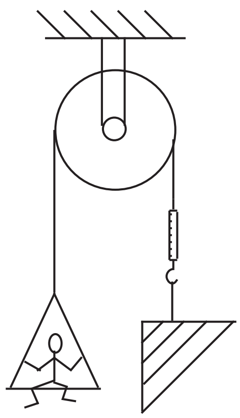


Figure 4.37

b.) spring scale (Figure 4.37) reading: ______
explanation:

c.) spring scale (Figure 4.38) reading: ______
explanation:

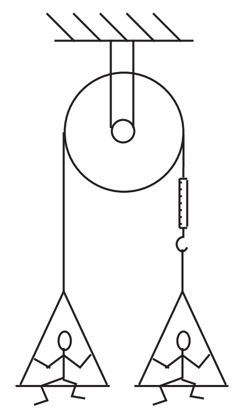


Figure 4.38

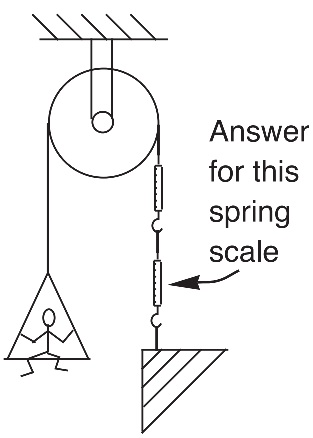


Figure 4.39

d.) spring scale (Figure 4.39) reading:______
explanation:

2.) If the invaders from another galaxy had two horses, some rope and a tree, what arrangement would be most effective to enable them to produce the maximum amount of force to pull Superman apart?

a.) Draw a diagram.

b.) Explain why your plan is best.

3.)

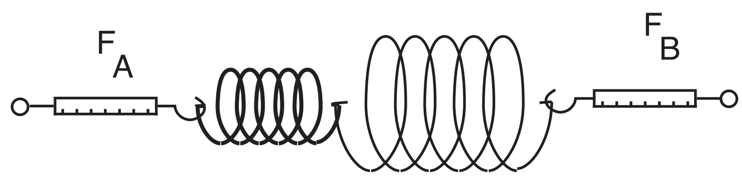


Figure 4.40

Two force measurers are being used to pull on a stiff spring on the left and a soft spring (like a slinky) on the right. The stiff spring stretches to twice its present length, and the soft spring stretches to 5 times its present length. Which force measurer will have the larger reading? Defend your answer clearly.

4.) A student sits on a swing which hangs from the ceiling as shown. If the student weighs 720 N, determine the tension in each of the two ropes labeled.

F_{T_1} = ______

F_{T_2} = ______

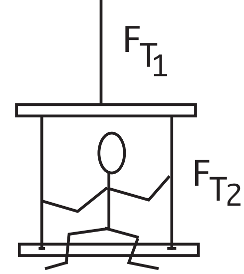


Figure 4.41

5.) A large cement block is sitting on a rough floor. Two students are pulling on it as shown, but the block does not move. The two spring scale readings are indicated.

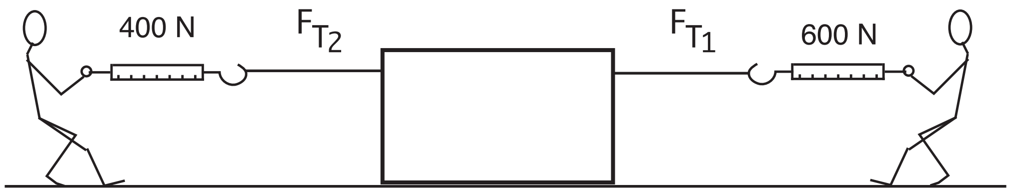


Figure 4.42

a.) Determine the tension F_{T_1} ______.

b.) What is the tension F_{T_2}? ______.

c.) How much friction force acts on the cement block? ______.

d.) What direction does the friction force vector point? ___________.

UNIT 5

Gravitational Force I

UNIT #5 – GRAVITATIONAL FORCE I

I. OVERVIEW OF THE GRAVITATIONAL FORCE I UNIT

A. MAJOR PRECONCEPTIONS POSING DIFFICULTIES IN THIS UNIT

1.) Causes or sources of gravitational force:

a.) Gravitational force is caused (or partly caused) by air pressure.

b.) Gravitational force is caused (or partly caused) by the rotation of the Earth.

c.) Gravitational force is caused by the Earth's magnetism or magnetic poles.

d.) Objects fall because they "want to go down". This is simply a natural tendency of objects which needs no further explanation.

e.) Only large objects (like planets or stars) cause gravity. Small objects do not exert a gravitational force (on either large objects or other small objects).

2.) Gravitational force is significantly different on different parts of the Earth (e.g. weaker in the southern hemisphere).

B. GENERAL STRATEGY OF THIS UNIT

While many teachers would see direct instruction on Newton's law of universal gravitation as the way to initiate teaching about gravity, we have discovered that students retain some of the more basic preconceptions listed above in spite of straight-forward "correct" instruction. Thus, the first day's lesson in this section is designed to specifically confront and examine the problems with these widely held preconceptions.

The Gravitational Force Interview homework that <u>preceeds the first lesson</u> is important for students and teachers. It reveals the wide range of preconceptions held by many members of the general public.

The second day's lesson endeavors to use the bridging strategy to introduce students to the notion of gravity as the invisible, two-way force that attracts pieces of mass of all sizes to each other. Once the threshold issue has been raised of whether there is a "critical mass" needed before gravitational forces arise, students should be ready to appreciate the evidence that gravitational forces even exist between small, ordinary objects like tennis balls.

C. **THE PHYSICIST'S VIEW**

This unit initiates the challenging task of helping students sort out some important features of mass. It may seem that understanding mass is simply a matter of presenting the quantitative ideas in the equation for the law of universal gravitation. However, we have found that certain qualitative preconceptions are such a major obstruction to the understanding of gravity that the first necessary goal is the creation of a qualitative foundation for the basic idea of gravitational force. The gravitational property of mass must eventually be differentiated from the inertial property of mass. Therefore, we feel the sequence Gravity I, Inertia I, Gravity II, then Inertia II has many advantages in the struggle to sort out and understand these two confusing and interrelated properties of mass. However, some teachers may wish to teach the Gravity I and II units in sequence for a number of practical reasons.

Some teachers may feel that these lessons devote too much time to struggle with the nature of gravitational force. For those who feel that way we recommend the article below:

Minstrell, J., & Kraus, P. (2005). Guided inquiry in the science classroom. In M.S. Donovan & J.D. Bransford (Eds.), *How Students Learn: History, Mathematics, and Science in the Classroom* (pp. 475-513). Washington D.C.: The National Academic Press.

As teachers, we need to recognize the great imaginative effort we are asking our students to make. The idea of gravitational force acting at a distance between all objects with mass is a very strange notion. In many situations, gravitational forces are very small, and within an atom it is about 10^{36} times smaller than the electrostatic force. In addition, we recognize that our students have always lived under the influence of gravitational forces and yet we want them to imagine what it would be like to be in a place with essentially zero gravity.

As teachers of physics, we readily accept the idea that any two units of mass are attracted by the gravitational force and readily apply the idea to atoms, falling objects, or stars. Figure 5.1 serves as a reminder that these three domains of gravitational interaction seem radically different to students.

Certainly we are starting students on a mind expanding adventure as we try to help them make sense of the intangible interaction between pieces of mass we call the gravitational force.

Three Domains of Gravitational Interaction

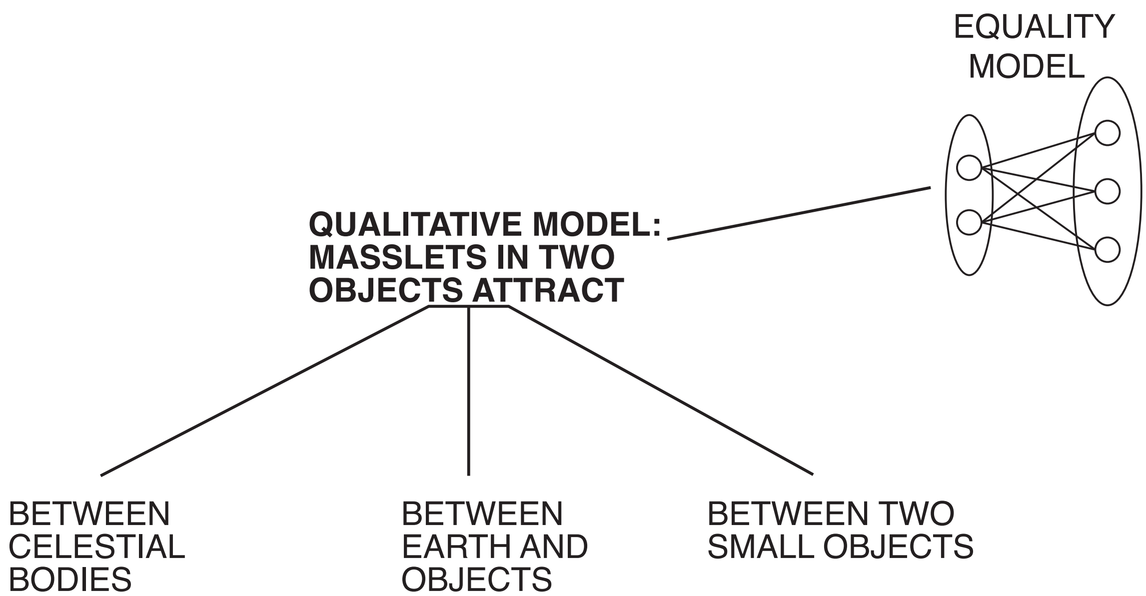


Figure 5.1

II. GRAVITATIONAL FORCE I – LESSON 1

A. OVERVIEW OF THE LESSON

It is strongly recommended that this first lesson be preceeded by the "Gravity Interview Assignment" which should be completed before the Day #1 lesson on the gravitational force.

The lesson begins by making a quick tabulation of the class results from the interviews.

The lesson continues by asking students to reflect about the nature of gravity as observed by humans on all parts of the planet. The notion that all people feel pulled toward the center of the Earth should be firmly established. Next, we move on to specifically confront common preconceptions that pose difficulties (Magnetism, Air Pressure, and Earth's Rotation). Finally, the lesson deals with the zero gravity environment so that students may enhance their concept of gravitational force after thinking about what it would be like to be in an environment with only very small gravitational forces.

B. MATERIALS

1.) Interview Homework sheet to preceed Day #1 class

2.) vacuum pump, spring scale, and mass hanging in a bell jar

3.) one marshmallow per class

4.) NASA video "Eating and Sleeping in Space"
select about 10-15 minutes of simulated micro-gravity material
website: www.core.nasa.gov
select: resources for education; then select: how to order
title: Eating and Sleeping in Space
item number: 006.3-04V
price: $16

5.) voting sheets

6.) globe and clay

7.) Homework sheets – Gravitational Force - Day #1

C. OBJECTIVES

1.) The student should understand that the Earth's gravitational force is essentially the same in magnitude on all parts of the Earth and that the pull is toward the center of the Earth from all locations on the Earth.

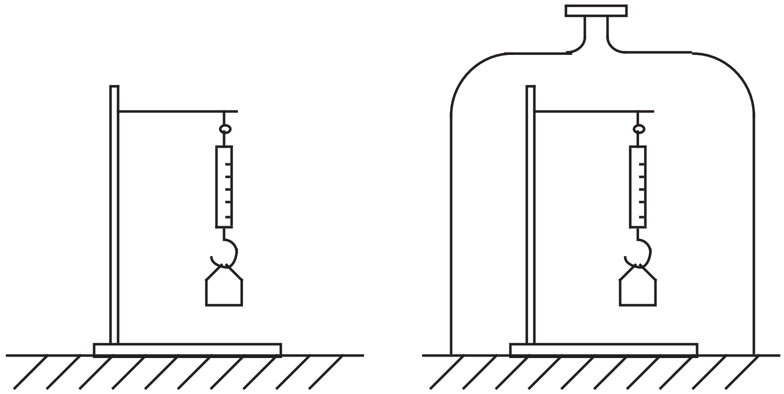
2.) The student should be able to visualize the consequences of the absence of gravity.

3.) The student should understand that the Earth's force of gravity is not an effect caused (or partly caused) by air pressure.

4.) The student should understand that the Earth's force of gravity is not an effect caused (or partly caused) by the Earth's rotation.

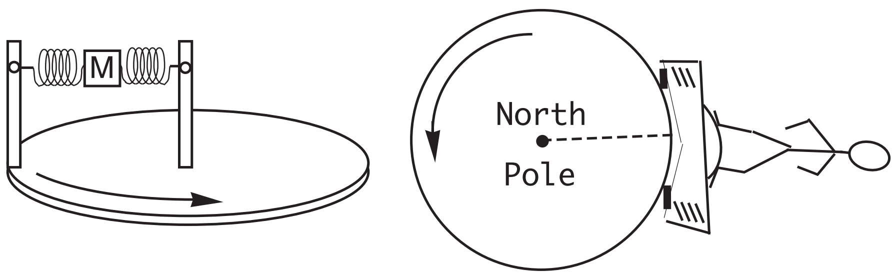
5.) The students should understand that the Earth's gravitational force is not a magnetic effect.

D. CONCEPT DIAGRAM – GRAVITATIONAL FORCE I - DAY #1



Air Pressure Demonstration

Figure 5.2



Earth Rotation Discussion

Figure 5.3

E. LESSON PLAN – GRAVITATIONAL FORCE I - DAY #1

1.) Gather and summarize the Interview data.

Discuss briefly the portions of the general public which are attracted to each of these views of the gravitational force.

Try to move on quickly, indicating that we will examine each of these widely held views about the cause of gravity.

2.) Present the diagram below and ask for comments.

Perhaps inquire if the 4 people in the diagram below feel approximately the same force.
A brief check for concerns here may be appropriate.

After some discussion summarize with the diagram (Figure 5.4) and state clearly that, "gravitational force points toward the center of the Earth."

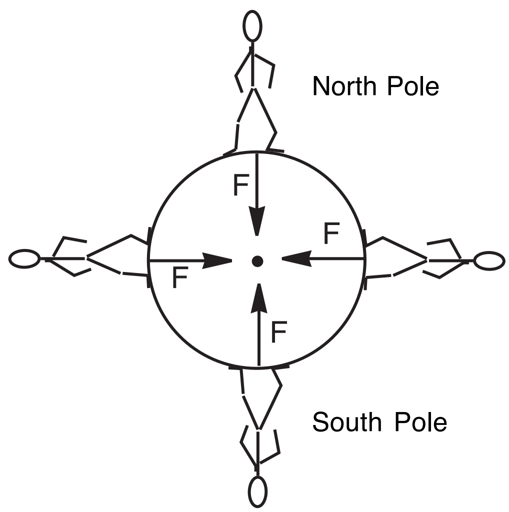


Figure 5.4

3.) Examination of magnetism as the cause of gravitational force

a.) Pass out sets of magnets for brief experimentation. Can you show that they both attract and repel from a distance?

b.) Discussion: How are these magnets similar to and different from the gravitational force?

4.) Elicit a conflicting preconception with Vote #1

a.) Draw the spring scale picture on the board (Figure 5.5). Explain that a metal mass is hanging from a spring scale that reads 10 N.

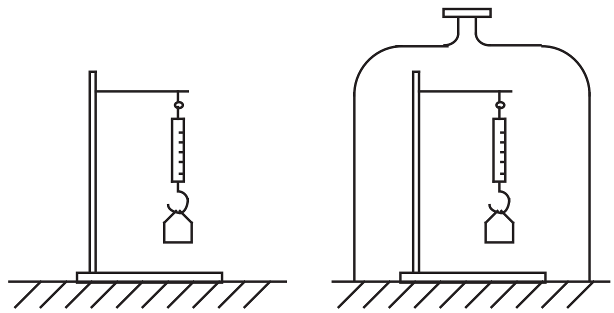


Figure 5.5

b.) *Question for Vote #1*

If we place the apparatus under a bell jar and we remove almost all of the air, what scale reading would you predict? Write the number of Newton's on your voting sheet.

c.) *Tabulate Vote #1 responses*

Make a table on the board to quickly record numbers of student responses in each range.

0 to 9, near 10, 11 to 20

With a public vote ask students to indicate what group they voted in.

d.) *Discussion of the air pressure vote*

Request students to defend their positions without attacking others. The teacher should:

- Draw out opinions from all groups.
- Avoid detailed excursions about buoyancy.
- Later ask students to critique the positions taken by other students.

5.) Demonstration with the vacuum pump[2]

a.) Use the vacuum pump to evacuate the bell jar while two or three students carefully watch the spring scale reading.

b.) *Discussion of the demonstration*

The teacher should withhold expressing a personal position during this discussion. To summarize the discussion the teacher should ask:

- Did the bell jar experiment tell us what causes the gravitational force?

- What did it tell us?

c.) *Challenge question and discussion*

"If the force of gravity is not caused by air pressure, then what does cause this force?"

Paraphrase helpful student comments and gently defer students' desire for the "right answer" by assuring them that it will become clear later.

[2] It is suggested that the vacuum pump remain hidden before the demonstration. If the vacuum pump does not have a pressure gauge, a marshmallow may be placed inside to provide some *evidence* that air is being removed.

6.) Probe for another preconception with Vote #2

a.) Draw a diagram on the board showing the "top view" of the Earth. (Also use an actual globe and stick a small object in a piece of clay on the Equator to represent the person. Rotate gently.)

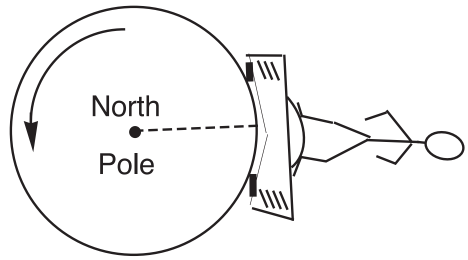


Figure 5.5

b.) *Vote #2 question - Earth's rotation*

"If we have a person, at the Equator, standing on a bathroom scale (show springs) how would the scale reading change if the Earth were to spin around on its axis much faster?"

Choices:

- Scale reads the same
- Scale reads more
- Scale reads less

7.) Discussion of Vote #2 (Earth's rotation)

a.) Draw out anchoring analogies from students. Perhaps hint about the rotor at the amusement park or merry-go-round at a playground.

b.) Draw Figure 5.7 on the board or demonstrate again with the globe and clay as needed.

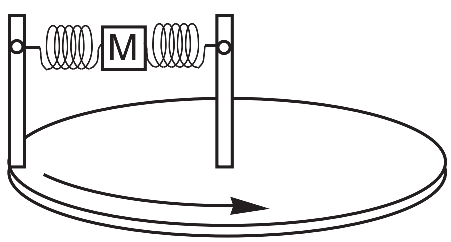


Figure 5.7

c.) *Summary question*

How would you respond to someone who says that gravity is caused by the rotation of the Earth?

Try to draw out and clarify student responses to this question.

8.) Show NASA video clip (about 10 minutes)

a.) Explain that you want to show the video to help students imagine what an environment with no apparent gravity would be like.

b.) (It is recommended that the discussion avoid the issues of micro gravity and free fall at this time. The common misconception that the space shuttle is beyond the Earth's gravitational attraction should be dealt with after the inertia concept has been carefully introduced.)

c.) Show a video with about a 10 minute segment selected from "Eating and Sleeping in Space" or another video made by astronauts in Earth's orbit.

9.) Summary of the lesson

The teacher should be sure that his/her position is clear on the following issues by the end of Day #1:

a.) Gravitational force is not caused by magnetism.

b.) Gravitational force is not caused by air pressure.

c.) Gravitational force is not caused by the Earth's rotation.

We will be moving on to examine the role of mass in the next lesson.

10.) Assign homework

a.) Assign Homework - Gravity I - Day #1

F. TEACHING NOTES – GRAVITATIONAL FORCE I - DAY #1

The lesson for Day #1 is primarily directed toward three preconceptions. This lesson is designed to carefully study these preconceptions to see that they do not make sense. It is not the intent of this first lesson to introduce a model for the gravitational force, but to start students reflecting about the nature of that force.

The portion of the lesson that deals with "microgravity" may seem unrelated. We feel, however, that students who have always lived in an environment with gravitational force need to think about the meaning of no force in order to appreciate the role of gravity in their every day lives.

Since this lesson is designed to maintain some tension, the teacher should withhold the physicist's position as long as possible. The wrap up section at the end is strongly recommended to make sure the teacher's position about these preconceptions is very clear. The homework following this lesson should also be a major part of building student confidence and bringing out points of confusion.

The bell jar demonstration has one messy issue worthy of note. A few students may realize that the small bouyant force of the air ceases when the air is removed. It would seem appropriate to acknowledge that this is correct but avoid a detailed discussion.

III. GRAVITATIONAL FORCE I – LESSON 2

A. OVERVIEW OF THE LESSON

This lesson begins with a review of homework from Day #1 and also a review of the summary statements from Lesson 1. Now that most students have set aside preconceptions about air pressure, magnetism, and the Earth's rotation, we are ready to take a closer look at how the gravitational force depends on the mass of objects.

Early in the lesson we focus on the question of gravitational force between two tennis balls and follow the discussion with a video of the Cavendish experiment as evidence that there is a gravitational force between ordinary small objects.

The lesson then moves on to examine the target question of the force of the tennis ball pulling on the Earth. The symmetry of the example of a duplicate Earth falling on the Earth is used as the anchor. The example of the Moon pulling on the Earth is used as a bridging case.

The summary section of the lesson pulls together the ideas that gravitational force is an attractive force that acts at a distance, that acts on all masses from very small to very large, and that has no simple tangible model to explain its origin.

B. MATERIALS

1.) voting sheets

2.) two tennis balls

3.) display setup of Cavendish torsion pendulum

4.) Best video you can obtain of the Cavendish Experiment
 Source 1: Website: http://www.physicscurriculum.com, referenced 20 September 2009.
 Physics Demonstrations in Mechanics, Part IV
 The last segment of the video is “Cavendish Experiment” (time lapse)
 VHS- $68 DVD- $7
 Source 2: Downloadable time lapse home video
 Website: http://www.fougmilab.ch/gravitational/foobar, referenced 20 September 2009.

5.) Homework sheets – Gravitational Force I - Day #2

C. OBJECTIVES

1.) To understand the consequences of the force of gravity as an interaction.

a.) The student should understand that the gravitational force is a two-way action that affects *both* objects in a pair.

b.) The student should understand that gravitational forces are exerted by all masses, *even very small ones*.

c.) The student should understand that the small force that attracts two tennis balls together is the same force that attracts people to the Earth, and attracts planets to stars.

2.) To appreciate gravitational force as a force acting at a distance.

The student should understand that a gravitational force acts at a distance and does not require close or direct contact like some other forces.

D. CONCEPT DIAGRAM – GRAVITATIONAL FORCE I - DAY #2

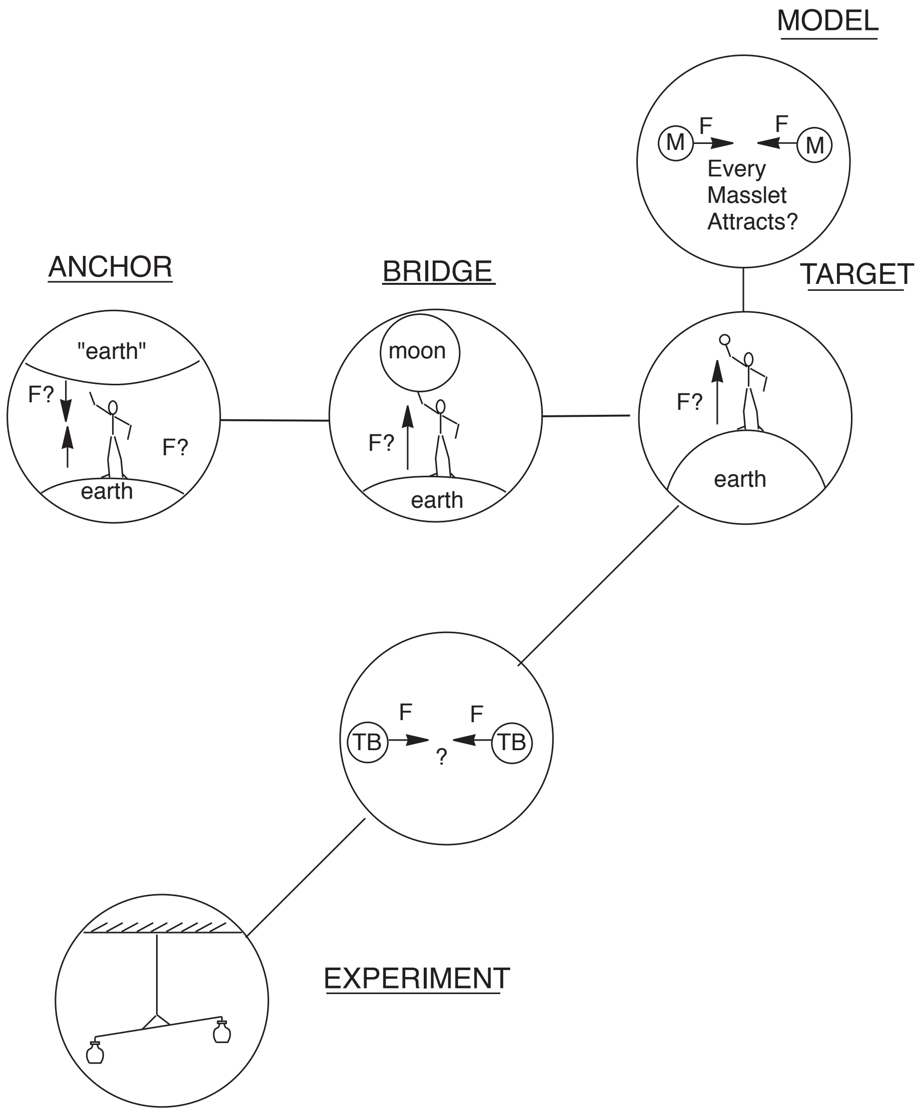


Figure 5.8

E. LESSON PLAN – GRAVITATIONAL FORCE I - DAY #2

1.) Review homework Day #1

a.) Deal with any questions about the Day #1 homework. Wrap up this and any other homework discussion with the observation that many people in our society (old and young) have strong views about gravity that physicists consider to be false. Some students may need reassurance about the confusion that has been introduced during this discussion. You should assure them that you will stick with them until they have a better understanding.

b.) Review the summary at the end of the Day #1 Lesson.

2.) Introductory focusing question

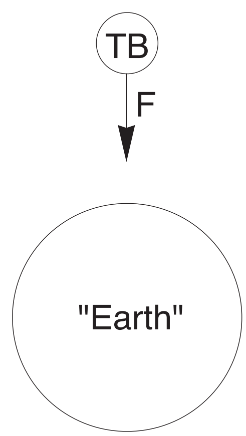


Figure 5.9

a.) Demonstrate dropping a tennis ball.

b.) Ask "Why does it fall?"

c.) Draw Figure 5.9 during the discussion and add in the force vector when appropriate.[4]

[4] If not stated earlier the teacher should acknowledge that mass is a cause of the gravitational force.

3.) Introduce Vote #1 (target question)

a.) Place two tennis balls on the lecture table.

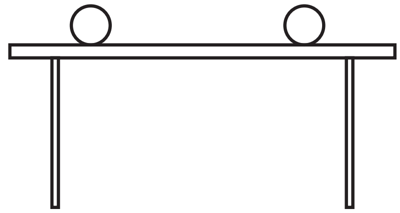


Figure 5.10

b.) *Vote #1 question*

Is there a gravitational force between these two tennis balls sitting on the desk?

c.) *Discussion of the target problem*

Sharing of student's positions on the question.

If the threshold issue (matter of some objects being too small in mass to cause gravitational force) does not come up in the discussion, the teacher may wish to introduce the question of gravitational forces between the two tennis balls again.

The instructor is encouraged to maintain a neutral role during this discussion. Try to clarify and paraphrase student comments. Point out the need for proof of gravitational forces between small objects.

The teacher might choose to ask students what limits their ability to observe the small gravitational effect between the two tennis balls. Then their ideas could be connected to the design of the Cavendish apparatus.

4.) Introduce the Cavendish apparatus (torsion pendulum)

Explain and demonstrate the sensitive nature of the torsion pendulum with a simple mock up. Emphasize the importance of this sensitive test for gravitational force between ordinary things. Be sure everyone understands how the equipment works.[5]

---

[5] It is important to show students a display version of the torsion pendulum so they can understand what is happening in the video (see Teaching Notes Figure 5.15).

5.) The Cavendish experiment

a.) *Show the video.*

Show one of the video presentations of the Cavendish experiment (see page 171). You may want to provide your own audio and stop the video occasionally to clarify what is happening.

b.) Discussion of the Cavendish video

Hopefully, the threshold issue will be clearly addressed during this discussion. If you feel many students are avoiding the issue, you might want to confront them with the optional vote below. In any case, you should check with the class to see if this filmed evidence, for gravity between every day objects, is convincing.

6.) Discussion question (optional)

a.) If you feel the class needs more time to struggle with the threshold issue or the problem of gravity between small masses, the following question (possibly a class vote) may be introduced.

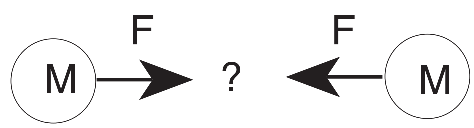


Figure 5.11

b.) *Question:*

Is there a gravitational force between the two identical tiny masses in the diagram? The teacher may choose to introduce the concept of tiny masslets at this point.[6]

[6] See the Teaching Notes for more detail about masslets.

7.) <u>Introduce Vote #2</u> (force of the tennis ball on the Earth)

a.) *Draw Figure 5.12*

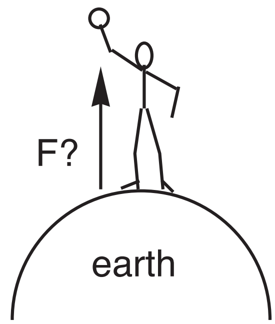


Figure 5.12

b.) *<u>Question Vote #2</u>*

If Atlas drops a tennis ball from one mile high, does the tennis ball exert a force on the Earth while it is falling? (Remind the class that the makes sense score is important to you).

c.) *Discussion of Vote #2:*

The teacher should try to remain neutral here, but help students share and clarify their ideas. Hopefully many students can reach the understanding that there must be a force, but it would be too small to move the Earth a measurable amount.

8.) Introduce the falling Earth question

a.) *Draw Figure 5.13*

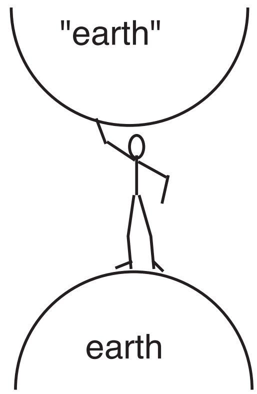


Figure 5.13

b.) *Question*

If Atlas goes to lunch and drops an object with the same mass as the Earth from one mile high, what will happen?

c.) *Discussion of falling Earth*

The teacher should try to elicit from the class the ideas that:

- both objects will exert equal forces.
- both objects will "fall" equal distances toward each other.

9.) Introduce Vote #3 (Force of the Moon on the Earth)

a.) *Draw Figure 5.14*

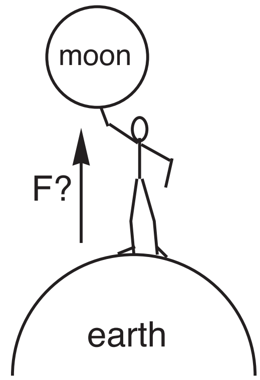


Figure 5.14

b.) *Question Vote #3*

If Atlas drops an object, with the same mass as the Moon, from 1 mile high, does the object exert a force on the Earth while it is falling? Explain why you chose your answer in the comment space.

c.) *Discussion of the falling Moon and tennis ball.*

Try to elicit from students the ocean tides as evidence of the Moon's force pulling on the Earth. Then present the question of the falling tennis ball again. This is a good item for Vote #4 if you have time.

10.) Summary of the lesson

Review these important aspects of a gravitational force:

a.) It acts at a distance.

b.) It attracts (never repels).

c.) Gravitational force is a two-way action.

d.) It penetrates vacuum or other matter.

e.) Gravitational force seems to work for both large and small masses.

f.) No simple intuitive model has been found to explain gravitational force.

11.) Assign homework

Homework – Gravitational Force I - Day #2

F. TEACHING NOTES – GRAVITATIONAL FORCE I - DAY #2

This lesson seeks to expand student's thinking about gravity by starting with the idea of gravitational forces between ordinary objects and the Earth. From that familiar setting we extend to examples of very small and very large objects. For some students it is hard to pull together such a wide range of cases under one central idea. The diagrams in this lesson are recommended to help students imagine what is being considered in each question.

Teachers who have worked with these lessons feel that the early parts of the lessons through the Cavendish experiment are very important. The later material provides valuable reinforcement for average classes. Those teaching stronger classes or those with longer teaching blocks may be able to deal with most of Day #1 and #2 in one session. Discussion of homework problems and the summary sections, however, should be valuable for all classes.

Some teachers who have not used the "masslet" idea or a similar concept earlier in the course may want to introduce the following summary as part of the lesson. We find it is helpful to think about a very small standard quantity of mass. One could think of this unit as equal to one of the following:

- a gram
- a standard kind of atom (say carbon)
- a nucleon (proton or neutron)

The name of such a standard unit of mass is not important, but we need to imagine these tiny units are identical in mass.

It is strongly recommended that the teacher make a simple mock-up of the Cavendish apparatus so all students can be crystal clear about what is happening inside the apparatus shown in the film. Teachers who have made this modest effort find that it helps to greatly increase student's understanding of this vital experiment. Tape recorder tape, a meter stick, and 2 small bottles seem to be very adequate. See Figure 5.15

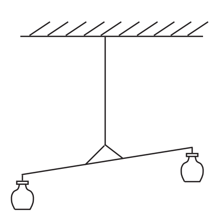


Figure 5.15

Some instructors with strong classes choose to move directly into work on the Law of Universal Gravitation using the Gravitational Forces II lessons. However, we strongly suggest that you consider inserting other material into your curriculum before starting Gravitational Forces II. The Inertia I unit will be effective here and one could work on problems involving the Gravitational force near the Earth's surface.

During these classes some students may complain that they have not been given a model or explanation of how gravity works. While it is safe to say that there seems to be no simple model or analogy that is extremely helpful, a few students may wish to know that there is a model that involves the curvature of space-time. This is intuitively helpful to those students interested in studying general relativity.

V. GRAVITATIONAL FORCE I – LESSON 3

A. OVERVIEW OF THE LESSON

This lesson is dedicated to a careful review of the homework from Day #2 and to wrap up the unit. It is especially important that the teacher check to see that the issues listed in the objectives of the lesson are covered.

B. MATERIALS

1.) Unit Quiz (if desired)

C. OBJECTIVES

1.) The student should understand that gravity's influence can reach through solid objects or empty space.

2.) The student should understand that the gravitational force and the magnetic force are different kinds of forces.

D. LESSON PLAN – GRAVITATIONAL FORCE I - DAY #3

1.) Discuss Homework – Gravitational Force I - Day #2

During the homework discussion it would seem it is especially important to emphasize the following issues:

a.) The comparison of gravitational forces with magnetic forces in question 5.

b.) Gravity is a force that acts between any 2 masses.

c.) We can not turn off or shield out the gravitational force.[7]

d.) Individual masslets pull on each other with a gravitational force.

2.) Summary presentation and discussion

a.) Question

What have we learned about gravity in the past three days?

b.) List contributions from the class on the board.

3.) Unit Quiz (if desired)

VI MATERIALS FOR DUPLICATION

A. Homework Problems

1.) Prelimary Homework (Interview sheet to preceed Day #1)

2.) Homework – Gravitational Force I - Day #1

3.) Homework – Gravitational Force I - Day #2

B. Quiz and Test Questions – Gravitational Force I

[7] There appears to be a widely accepted myth that NASA has some sort of special gravity free room.

PRELIMINARY HOMEWORK - GRAVITATIONAL FORCE - DAY #1

Name: ____________________

Period: _____Date: __________

For your assignment before our next class you are to interview two people who are not physicists or engineers. In order to increase age diversity, try to include one person between ages 12 and 20 and another person over age 20. A telephone interview of a relative or friend would be acceptable.

The following questions are offered for your interview. Try to serve as an objective interviewer in order to record the position of the person you are interviewing without revealing your beliefs on the subject. Try to record the responses neatly so the results can be tabulated.

INTERVIEW QUESTIONS	PERSON 1 AGE: ____	PERSON 2 AGE: ____
What causes gravity?		
Is gravity caused or partly caused by the Earth's rotation?		
Is gravity caused or partly caused by the air pressure from the atmosphere?		
Is gravity caused or partly caused by magnetism or the Earth's magnetic poles?		
Is there a way to shield out the gravitational force (create a gravity free room)?		

HOMEWORK - GRAVITATIONAL FORCE I - DAY #1

Name: ____________________

Period: _____Date: ___________

1.) If you were to seal this room and force in extra air to increase the air pressure, describe the changes you would expect in the following:

a.) Your bathroom scale reading (Note that it is just a platform that sits on springs).

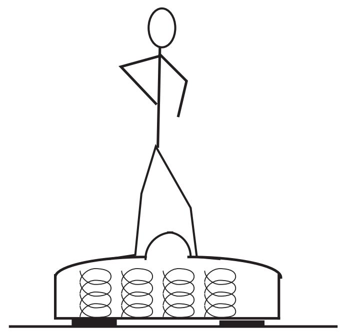


Figure 5.16

b.) The reading of a weight on a hanging spring scale.

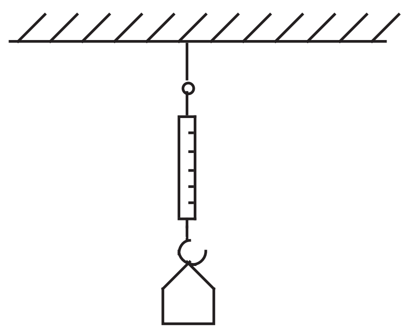


Figure 5.17

c.) The gravitational force acting on your body.

2.) If the Earth were to completely stop spinning on its axis:

a.) How would its gravitational force change?

b.) Would spring scale readings (at some latitudes) be affected? Explain.

3.) If you were to *gently* throw a raw egg to a friend in a space ship (in zero-g), what would you predict to be a common error? (Assume you have not been able to practice.)

Figure 5.18

4.) If a friend were to tell you that the force of gravity is caused by the Earth's magnetic influence, what explanations or demonstrations would you use to try to change your friend's mind?

HOMEWORK – GRAVITATIONAL FORCE I - DAY #2

Name: ____________________

Period: _____Date: __________

1.) A truck full of rocks is parked ten feet from a one-quart bottle of water.

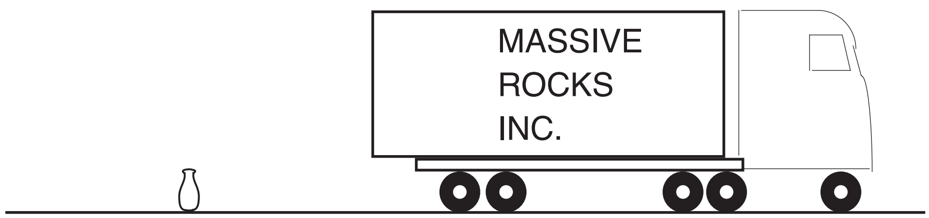


Figure 5.19

a.) Does the truck pull on the water with a gravitational force?

b.) Does the water pull on the truck with a gravitational force?

c.) If you said yes to either question, how would you convince a friend who does not believe you?

2.) An airplane flies overhead one morning while you are standing on your bathroom scale. Would you expect your scale to read more, less, or the same as the usual reading during the moment the plane is directly overhead? Defend your answer.

3.) If the ground under your house were hollowed out by a coal mine operation, (as is true in some towns in Nevada) how would you expect that to affect your weight as measured on your bathroom scale? Defend your answer.

4.) When talking with a friend about the tennis balls on the table problem, your friend insists that there is no way there could possibly be any gravitational force between two tennis balls six inches apart on a flat table. How would you try to convince your friend that she/he is wrong? Explain.

5.) Many people think magnetism and gravity are the same idea. Give two reasons you would use to convince someone they are actually different.

a.)

b.)

6.) Can you think of something you can place between the two tennis balls on a desk that would shield out the gravity force between them?

7.) Many people believe that there is a "gravity-free room" at NASA. Can you explain why this is impossible?

8.) If Atlas drops an object with three times the Earth's mass from one mile high, describe the resulting forces and motions of the two objects.

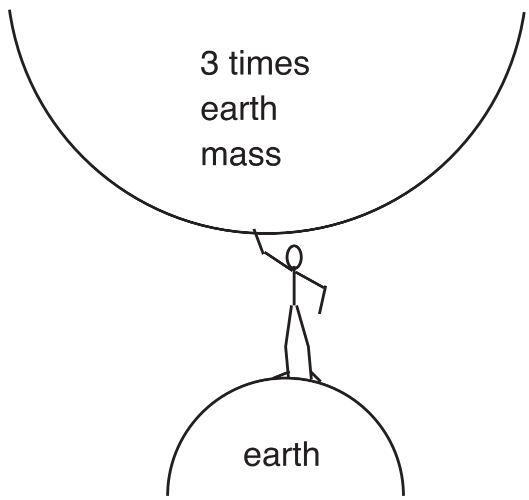


Figure 5.20

9.) What are the smallest objects you can imagine that are gravitationally attracted?

____

10.) What are the largest objects you can imagine that are gravitationally attracted?

____

11.) What is not attracted by gravity?

____

12.) a.) Is the Earth attracted to a falling tennis ball?

____

b.) Would you expect the Earth to move toward the tennis ball a measurable amount?

____

QUIZ AND TEST QUESTIONS – GRAVITATIONAL FORCE I

1.) In class we saw a demonstration of the effect of decreasing air pressure on a spring scale reading.

a.) Describe an experiment to test the effect of increasing air pressure on a spring scale reading.

b.) What would you expect the results of this experiment to be? Explain.

2.) Write a brief paragraph explaining why the rotation of the Earth cannot be used as an explanation for the cause of the force of gravity.

3.) What evidence do we have that there is a gravitational force between *any* two masses (even very small ones)?

4.) You are standing on your bathroom scale one morning when the Earth suddenly loses all of its atmosphere (all the air is gone).

a.) Would you expect the scale reading to increase, decrease, or stay the same? __________________________

b.) If it changes, about how much would it change? ______________________

c.) Explain your answer.

5.) Would your scale reading on a bathroom scale change if you got weighed next to a really big building or a really big mountain? ________________________ Explain your answer.

6.) If the Earth started spinning around on its axis much faster so it went around once every six hours instead of once every 24 hours,

a.) How would the pull of the Earth's gravitational force on your body change? (increase, decrease, stay the same). ____________________ Explain.

b.) How would the scale reading on your bathroom scale change? (increase, decrease, stay the same). ____________________ Explain your answer.

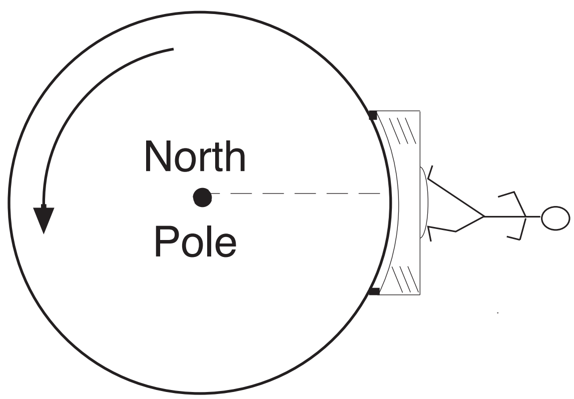


Figure 5.21

7.) If two Earth-size planets were held one mile apart by strong posts, how would it feel to the person standing on the "bottom" Earth?

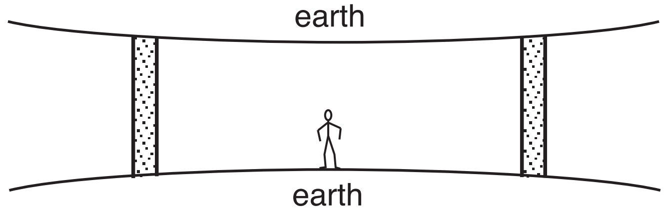


Figure 5.22

UNIT 6

Gravitational Force II

UNIT #6 - GRAVITATIONAL FORCE II

I. OVERVIEW OF THE GRAVITATIONAL FORCE II UNIT

A. MAJOR PRECONCEPTIONS POSING DIFFICULTIES IN THIS UNIT

1.) Interactions of objects

a.) A large mass pulls more on a small mass than a small mass pulls on a large mass.

b.) When two gravitational forces act on a third body only the larger force has an effect.

c.) The gravitational force an object exerts depends only on its own mass and not on the mass of the object on which it is exerting a force.

B. GENERAL STRATEGY OF THIS UNIT

In spite of clear instruction to the contrary, many teachers will find that students retain the notion that the third law does not apply to gravitational forces between very different masses. This unit builds student understanding of the Law of Universal Gravitation starting with individual masslets. Building on the belief in the gravitational force between small objects established in the earlier *Gravitational Force I,* the argument is developed for equal and opposite gravitational forces. In order to insure that students grasp the significance of the equal and opposite force pattern, we consider examples in the three domains of gravitational forces from the *Gravitational Force I.*

In the second lesson, this unit continues to examine the Law of Universal Gravitation by using the masslet model to illustrate the significance of the product of the two masses. Finally, the inverse square pattern is developed through a diagram and a demonstration to help students grasp the effect of distance on a gravitational force.

C. **THE PHYSICIST'S VIEW**

It is suggested that students have prior experience with not only the *Gravitational Force I* lessons but also the *Inertia I* lessons. Once students have had an initial exposure to both the gravitational and the inertial properties of a unit of mass (masslet), the second round of exposure to these ideas should help consolidate them. The instructor should be watchful for opportunities to help students sort out confusion between these two concepts.

The other major concern in these lessons is the issue of modeling the gravitational force between two masslets. While there is no simple physical model that adequately represents the many aspects of the gravitational force, the process of struggling with the nature of the gravitational force and comparing it with some models will help students grasp important aspects of gravitational force.

As the teacher approaches the end of the Day #2 lesson, the Law of Universal Gravitation begins to take shape. Should you wish to push on and introduce the Universal Gravitation Law with standard units, be advised that students will need practice in all three domains of gravitational force problems considered earlier:

- Gravitational force between small objects
- Gravitational force between a small object and the Earth
- Gravitational force between celestial bodies

II. GRAVITATIONAL FORCE II – LESSON 1

A. OVERVIEW OF THE LESSON

The lesson uses a bridging analogy strategy to convince students that objects with different masses pull on each other with equal and opposite forces. The truck and the water bottle problem is used as a target and two identical masslets are used as the anchor (see the concept diagram).

In the bridging section of the lesson considerable effort goes into constructing a mental model using concrete objects (elastic bands) to represent the forces caused by the invisible interaction between the two masses. The lesson proceeds to argue that the force (number of bands) would depend on the product of the number of masslets and that other neighboring masses should not affect the force between two objects. Finally, the convenience of the center of mass notion for large objects is introduced to help simplify the problem of dealing with large masses.

B. MATERIALS

1.) voting sheets

2.) three pieces of wood with nails and long rubber bands

3.) Homework sheets - Gravitational Force II - Day #1

C. OBJECTIVES

1.) To understand the consequences of gravitational force as an interaction.

a.) The student should visualize a small standard piece of mass (a "masslet") as the unit involved in gravitational interactions.

b.) The student should understand that gravitational force is a two way action that affects both objects in a pair.

c.) The student should understand that the gravitational forces acting between any pair of masses are equal in magnitude and opposite in direction.

d.) The student should understand that the gravitational force between two objects is a function of the number of masslets in each object (quantitatively this function is a product).

2.) To develop some facility for reasoning about gravitational force using analogies.

a.) The student should understand that analogies such as springs, magnets and rubber bands can help us think about some characteristics of gravitational force.

b.) The student should be able to state the limitations of such analogies.

3.) To understand that gravitational force continues to act between bodies, even when a much stronger force may be acting on one or both bodies.

D. **CONCEPT DIAGRAM - GRAVITATIONAL FORCE II - DAY #1**

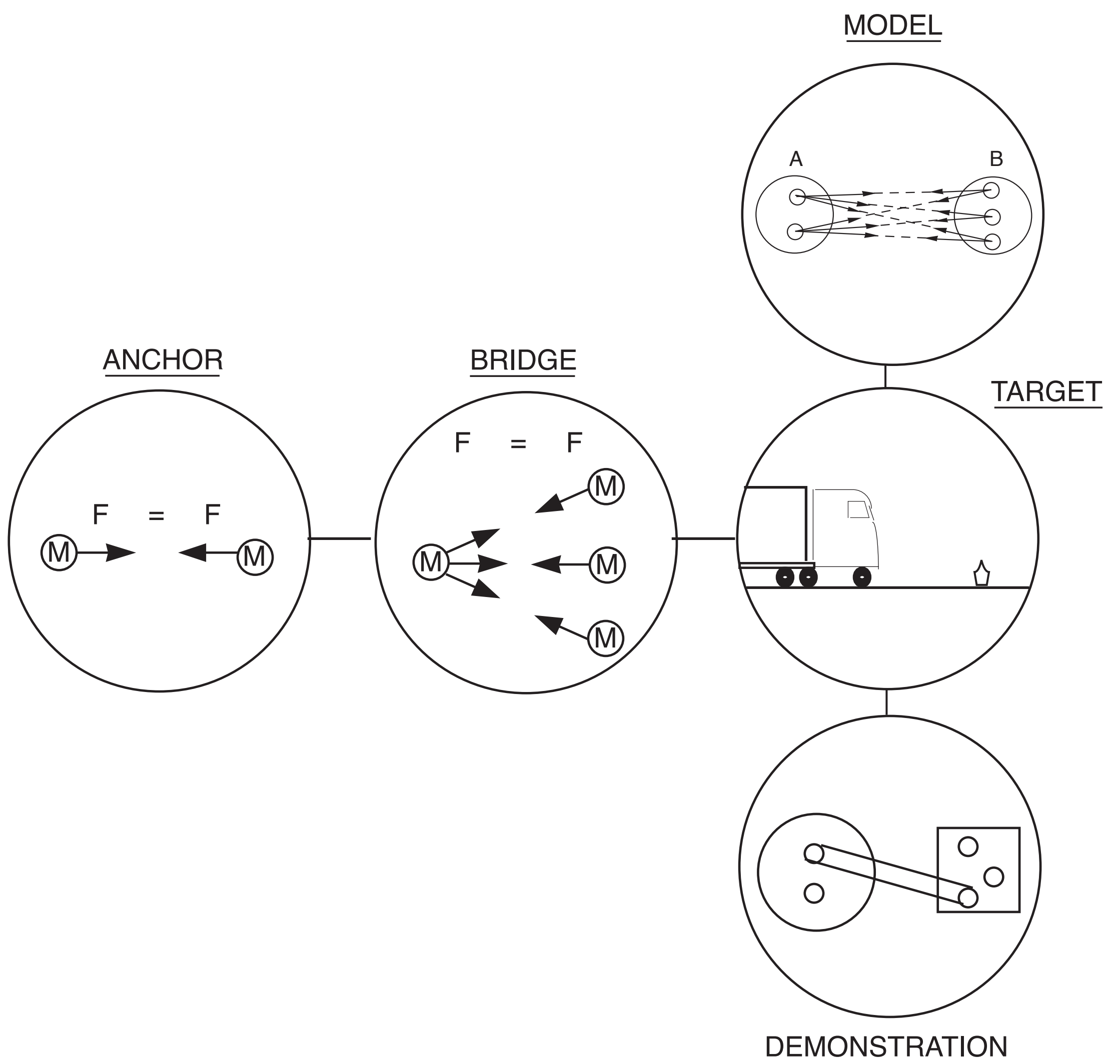


Figure 6.1

E. LESSON PLAN - GRAVITATIONAL FORCE II - DAY #1

1.) Introductory vote on the target problem

a.) Draw the picture.

b.) The question - Vote #1

Comparing the gravitational force of the big truck on the little water bottle and the little water bottle on the big truck, which force is larger?

c.) Choices:

- $F_{T\ on\ W} > F_{W\ on\ T}$
- $F_{T\ on\ W} = F_{W\ on\ T}$
- $F_{T\ on\ W} < F_{W\ on\ T}$

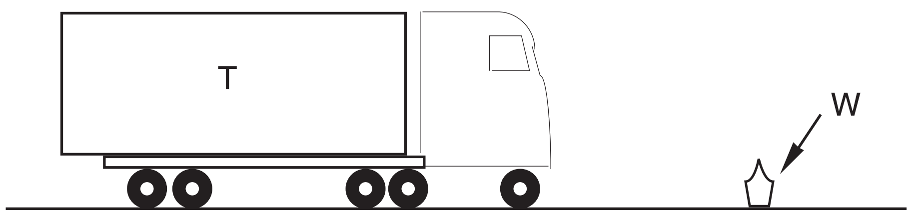


Figure 6.2

2.) Discussion of Vote #1

a.) Draw out student opinions and statements on the vote question. Ask that they initially defend their own position and later challenge other's ideas. Inquire about how many feel their answer makes little sense.

b.) *Possible challenge question*

If too many people seem to be voting equal with little confidence, try the process of direct challenge such as: "How could that little bottle possibly pull on the big truck as hard as the big truck could pull on the little bottle?"

3.) Introduce or review the masslet concept

a.) We have found that the idea of a 'masslet' (small, standard quantity of matter) is helpful in thinking about properties of matter. Consider the following possible masslet units.

- a gram
- an atom (point out different size atoms could cause trouble).
- a nucleon (neutron or proton - since these make up the vast majority of the mass of each atom, not a bad standard piece of matter).

b.) After brief discussion suggest that a gram size piece of matter is quite small and it would make a good standard for our visualizable 'masslet', although other standard units of mass might be preferable for very large or very small objects.

4.) Vote on the anchor problem

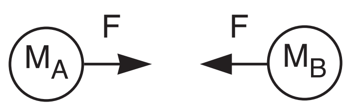


Figure 6.3

a.) Draw the diagram above (Two identical masslets).

b.) The question - Vote #2

Considering the gravitational force between masslet A and masslet B, which of the following is true?

- $F_{A\text{ on }B} > F_{B\text{ on }A}$
- $F_{A\text{ on }B} = F_{B\text{ on }A}$
- $F_{A\text{ on }B} < F_{B\text{ on }A}$

c.) Indicate also that the makes sense score is important.

d.) Only a brief discussion should be needed.

5.) Development of a mental model for force between masslets

a.) Discussion question

What sort of mental tangible model can you imagine to help visualize the equal forces acting between these masses? Try to elicit or eventually suggest such things as *invisible*:

- strings
- rubber bands
- springs
- bubble gum strands

6.) Demonstration of the rubber band model

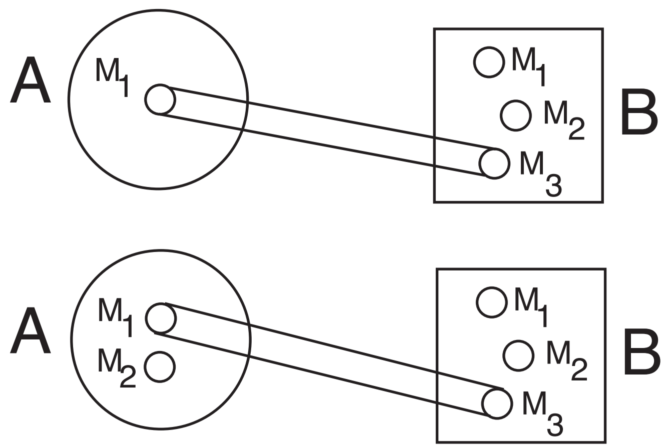


Figure 6.4

Using two pieces of wood with one nail in one and three nails in the other (to represent masslets), stretch three rubber bands across and hook up each pair of masslets with a band. Then demonstrate the second example using 2 masslets and three masslets with six rubber bands. Emphasize the idea that this is a tangible representation of an invisible interaction in which each masslet in block A attracts each masslet in block B. It will probably be necessary to have two students hold the pieces of wood while you connect the rubber bands.

Please notice that the diagrams were simplified by drawing one rubber band in each case.

7.) <u>Examining third body interference (Optional)</u>

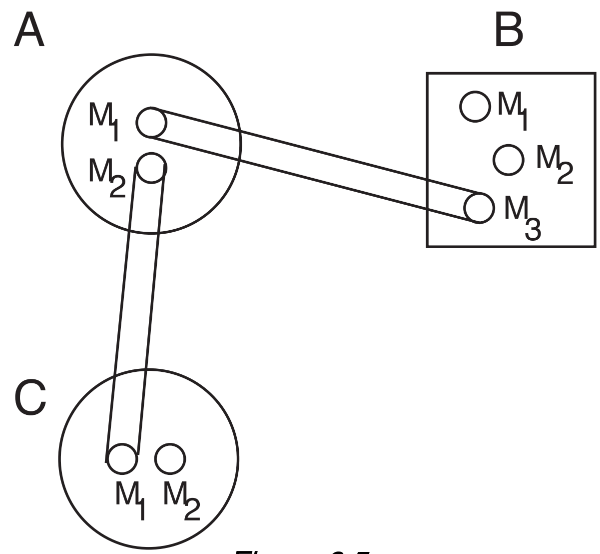


Figure 6.5

a.) Add the third body to the earlier diagram. Note that all bands are not shown.

b.) Question: Does the presence of body C change the behavior of the 6 bands between bodies A and B?

The presence of a third body may cause a lot of struggle. You may want to demonstrate with a third wood block with two nails and more rubber bands.

8.) <u>Critique of mental models</u>

Take time to examine the good and bad points about each of the models/analogies suggested above. Be *sure the class realizes that each of these analogies has a serious weakness.* For example:

a.) Tangible models for *invisible* action at a distance forces.

b.) *Increasing distance increases the force* in most of these examples.

c.) You may wish to say that science has no agreed upon, easily visualized, model of gravitational forces.

9.) Vote on the interacting masslets model

a.) Introduce the vote by drawing the two small objects. A has two masslets, and B has three masslets. Draw lines with arrows for B pulling on A and then with *another color* draw lines for A pulling on B (six lines each way).

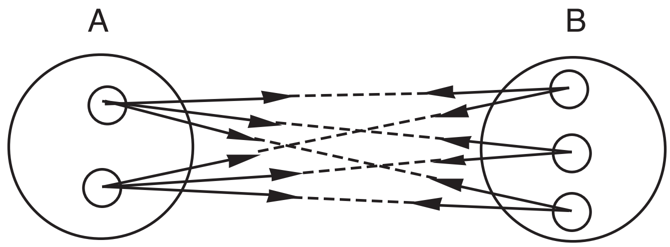


Figure 6.6

b.) The question - Vote #3

Which object exerts a larger gravitational force?

- 2 on 3
- 3 on 2
- equal forces

Note: the makes sense scores were the primary reason for this vote.

c.) *Discussion of Vote #3*

There may still be some need for clarification or some concern about an extreme case. Perhaps ask again for a volunteer with a low makes sense score.

d.) In any case, the teacher needs to affirm the correct answer and explanation here.

e.) After the discussion ask the class how to calculate the number of bands that would be needed to connect three masslets to four masslets.

10.) Present the problem of a person's Gravitational Force pulling on the Earth

a.) Draw Figure 6.7 and explain it.

A person standing on the Earth weighs 800 N. This means the Earth is exerting a gravitational force on the person of 800 N.

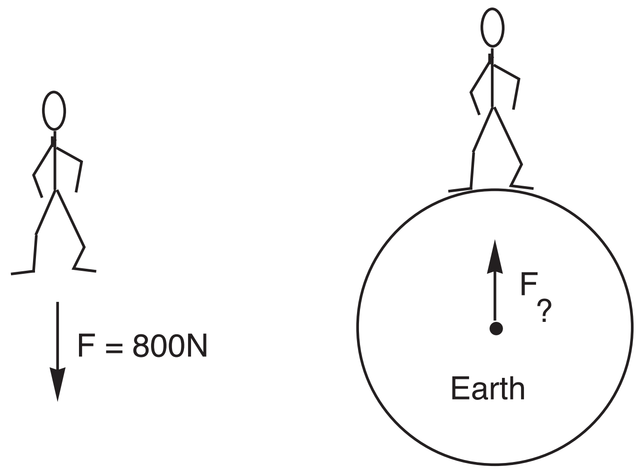


Figure 6.7

b.) The question - Vote #4

Does the person exert any upward gravitational force on the planet Earth? Yes or No. If Yes, how much?

(Be sure to emphasize that this question is not asking if the person exerts a downward force on the ground, *but* if the person exerts an upward gravitational force on the planet Earth.)

Answer choices:

- No force
- Some force, but less than 800 N
- 800 N
- More than 800 N

c.) Discuss the vote and try to help out students who have a low makes sense score.

If some students seem to be struggling a lot during the discussion you may wish to introduce a masslet diagram with the person as one masslet and the Earth as ten masslets. Then start drawing in the lines between masslets.

11.) The effect of changing one mass (Optional section)

a.) Draw Figure 6.8 (two masslets and three masslets) and ask what will happen to the forces if one masslet is removed from B.

b.) The question - Vote #5 (perhaps a public vote)

Will the force of A on B change if a masslet is removed from B? (Illustrate by erasing one masslet in B, and stress that the question is asking about the force that A exerts on B.)

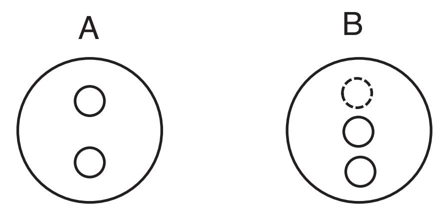


Figure 6.8

c.) Choices:

- $F_{A \text{ on } B}$ will increase.
- $F_{A \text{ on } B}$ will decrease.
- $F_{A \text{ on } B}$ will remain the same.

d.) Discussion of the vote

If most students vote that the force of A on B will decrease, the teacher could challenge them with: "But A is still just as strong, it still has the same number of masslets."

12.) Homework

Assign Homework – Gravitational Force II - Day #1.

F. TEACHING NOTES - GRAVITATIONAL FORCE II - DAY #1

If you find that some students seem really skeptical about the equality of forces issue, it may help to use the blocks of wood connected by rubber bands and have a student with closed eyes hold one in each hand to feel that the forces are equal.

III. GRAVITATIONAL FORCE II LESSON – LESSON 2

A. OVERVIEW OF THE LESSON

After careful consideration of any difficult points on the homework, this lesson shifts to the development of the general form of the Law of Universal Gravitation. The product of the masslets notion is reviewed first, and then the inverse square relationship for distance is developed. Finally the ideas are combined into one function.

B. MATERIALS

1.) overhead projector

2.) large paper with square cut out for the overhead projector

3.) square paper to match the initial lighted square area on the screen

C. OBJECTIVES

1.) The student should understand that the gravitational force varies inversely as the square of the distance between the centers of the attracting masses.

2.) The student should be able to solve problems about the gravitational force in which both mass and distance are variables.

D. LESSON PLAN - GRAVITATIONAL FORCE II - DAY #2

1.) Discuss homework questions from Day #1

Give special attention to problems 2, 5 and 6 to assure that the critical issues are confronted in these problems.

2.) Multiplicative relationship

a.) This issue may have been dealt with adequately if there was an extended discussion of homework problem 1. However, the following question and discussion may be helpful *if you feel the class needs more work on the issue of the product* of the masslets determining the force of gravitational force.

b.) *Question with masslets*

How does the total gravitational force (number of force arrows) depend on the two masses? Consider a new example:

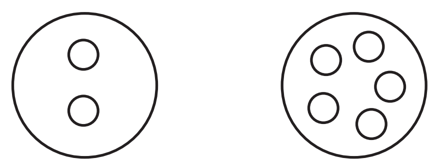


Figure 6.9

c.) Review the idea of rubber bands or other spring type models the class liked (as may seem necessary).

d.) What is the mathematical pattern in the total number of arrows (force lines)? Draw out the idea that $F \propto (m_1 \times m_2)$. That is, the number of force arrows (in each direction) depends on the product of the number of masslets in each object.

3.) Introduce the inverse square distance relationship

a.) Introduce the idea of the gravitational force's variation with distance as a new concern.

b.) Construct the diagram (Figure 6.10) indicating how the gravitational influence of one masslet must spread out in space.

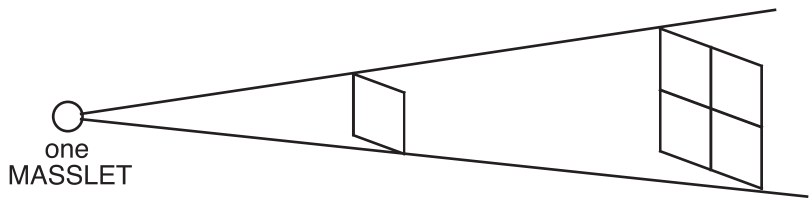


Figure 6.10

4.) Demonstrate the inverse square function

a.) Cover the overhead projector surface with a paper that has a small square cut out of the middle. Then hold a square piece of paper on the screen whose area equals the lighted region. Finally back up the overhead projector to twice the distance and show that four pieces of paper will be needed on the screen. Ask what would happen if you triple the distance or halve the distance. Propose that the way in which light intensity decreases with distance is analogous to the way in which gravitational force intensity falls off.

5.) Discussion combining mass and distance

After the demonstration, discuss the gravitational force models such as rubber bands, gum, etc. with the added distance problem in mind. Students should be able to identify some of the limitations for each of the gravitational force models. Acknowledging that no model is perfect, move on to establish the general pattern that the force of gravitational force should depend on the function

$F \propto m_1 m_2 / R^2$.

6.) Review of the general pattern

After constructing Figure 6.11 review the ideas that:

a.) This pattern works in all three domains of gravitational interaction.

b.) The distance is measured from the center of mass of one object to the center of mass of the other (not proven here).

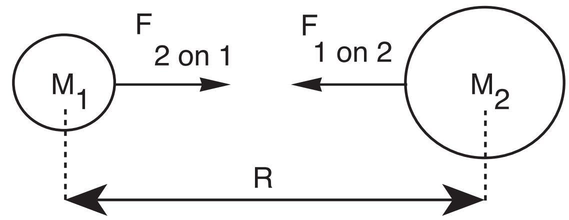


Figure 6.11

7.) Homework

Assign Homework - Gravitational Force II - Day #2.

E. TEACHING NOTES – GRAVITATIONAL FORCE II – DAY #2

Teachers are reminded that the non-calculus version of the law of universal gravitation is only accurate for spherical objects or objects that are far apart. Using the law for problems similar to the “truck and the water bottle” certainly gives only approximate values.

IV. MATERIALS FOR DUPLICATION

A. HOMEWORK PROBLEMS

1.) Homework - Gravitational Force II - Day #1

2.) Homework - Gravitational Force II - Day #2

B. QUIZ AND TEST QUESTIONS - GRAVITATIONAL FORCE II

HOMEWORK - GRAVITATIONAL FORCE II - DAY #1

Name: ____________________

Period: _____Date: __________

1.)

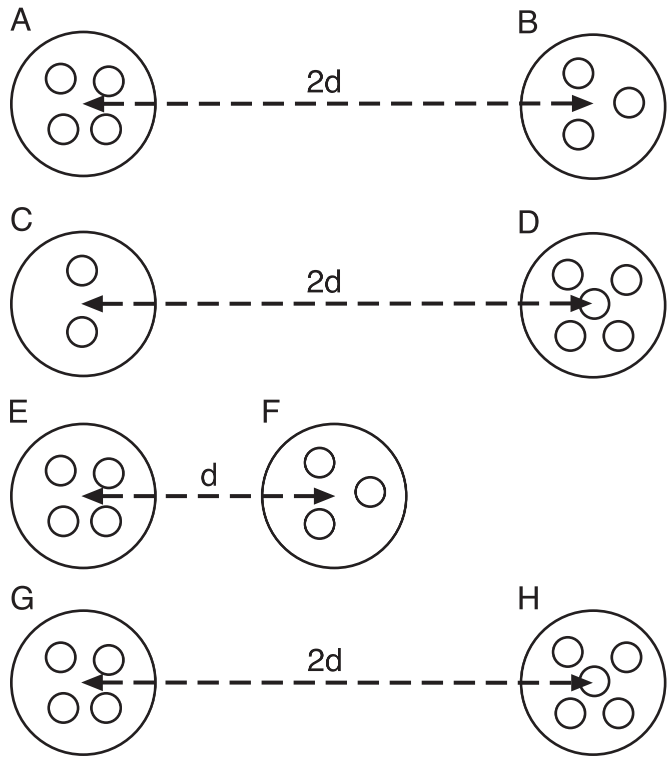


Figure 6.12

Each of the objects above have the number of masslets pictured. For each of the pairs of gravitational forces below, place a sign between them (>, <, or =) to indicate how they compare, and give a reason for your answer.

$F_{A \text{ on } B}$ _______ $F_{B \text{ on } A}$ reason: ____

$F_{A \text{ on } B}$ _______ $F_{C \text{ on } D}$ reason: ____

$F_{C \text{ on } D}$ _______ $F_{E \text{ on } F}$ reason: ____

$F_{A \text{ on } B}$ _______ $F_{G \text{ on } H}$ reason: ____

2.) If a feather is sitting on a planet, most people would probably agree that the gravitational force from the planet is pulling on the feather. How would you convince a skeptic that the feather must also be pulling on the planet?

3.) In which case would you expect a larger gravitational force between a truck and a building?

a.) A 5 ton truck parked next to a 20 ton building.

b.) A 4 ton truck parked next to a 30 ton building.

What assumptions do you have to make to solve this problem?

4.) Scientists in Isaac Newton's time (1600's) thought that it was ridiculous to believe that the Moon, which is much smaller than the Earth, could exert the same size gravitational force on the Earth as the Earth exerts on the Moon. If you were transported back in time, what arguments would you give to convince them that these forces are equal?

5.) What do you feel is the best thing to use as a tangible model for the gravitational force between two masslets?

a.) Why do you like your model?

b.) What do you see as its weaknesses?

6.) If a person jumps off a cliff, the person is pulled down toward the Earth by gravitational force. The Earth should experience an equal upward force caused by gravitational force. Would you expect the Earth to move up some to meet the falling person? Explain.

7.) It is hard for many people to believe that a massive object with a million masslets pulls on a small object of two masslets with a force equal to the force of the tiny object on the massive object. How could you argue logically that the forces must be equal?

8.) Two large bowling balls are hanging from ropes and they feel a small gravitational force attracting them.

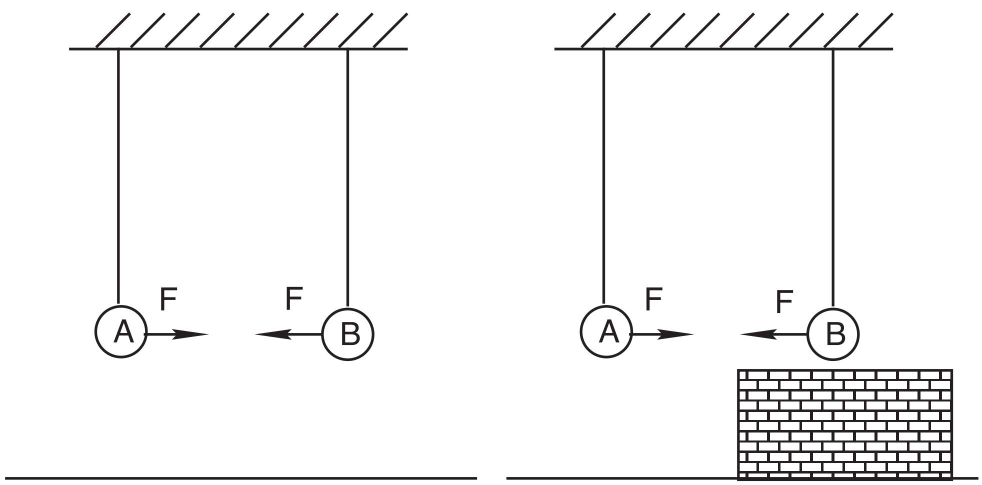


Figure 6.13

a.) How would you expect the gravitational force of A pulling on B to change when a massive cement block is placed under B?

b.) Is there some sort of wall or *shielding material* that you could place between A and B to shield out the gravitational force between A and B?

HOMEWORK - GRAVITATIONAL FORCE II - DAY #2

Name: ____________________

Period: _____Date: __________

1.) If we take one masslet away from the eight masslet object and give it to the two masslet model, by what ratio will the amount of gravitational force between the two objects change?

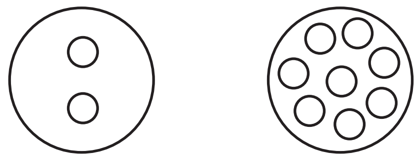


Figure 6.14

2.) If we imported enough mass from Jupiter to make the Moon three times as massive,

a.) By what ratio would the force of the Moon pulling on the Earth change?

b.) What effect would this change have on the ocean tides?

3.) If the mass of the Moon were increased to three times its present size and the distance to the Moon increased to twice the present distance, how would the gravitational force attracting the Moon to the Earth change?

a.) • increase • decrease • stay the same

b.) Find the ratio of the new force to the old force.

4.) If the Moon could be moved, by what ratio would the gravitational forces between Earth and Moon be changed under the following conditions:

a.) Moon moved three times as far away.

b.) Moon moved to one third as far away.

c.) Moon moved two times as far away and Moon's mass increased to four times its present mass.

5.) Explain what is wrong with the masslet diagram for gravitational force between the three objects shown below:

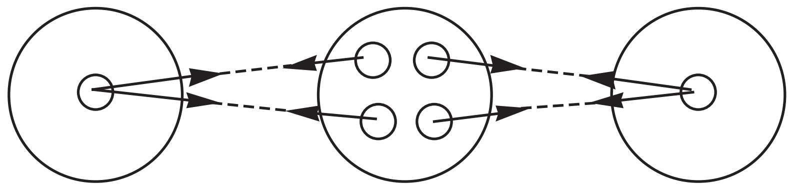


Figure 6.15

6.) Considering the diagram Figure 6.16 indicate how the *force of B acting on C* will change under each of the following conditions:

a.) A changes to two masslets ____________.

b.) B changes to one masslet ____________.

c.) C changes to four masslets ____________.

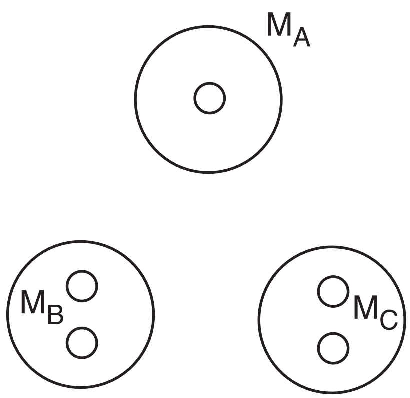


Figure 6.16

7.) A student wishing to investigate how air pressure affects gravitational force weighs a book at home and then climbs to the top of a very high mountain to weigh it again. The student has been told the air pressure is very low on top of the mountain. What is wrong with this student's reasoning?

V. <u>QUIZ AND TEST QUESTIONS - GRAVITATIONAL FORCE II</u>

1.) Compare the gravitational force the Sun exerts on the Earth with the force the Earth exerts on the Sun. Which is larger, or are these forces the same size? Explain.

2.) Consider the student, who weighs 500 N due to the Earth's gravitational force, when the same student goes to Saturn which has 100 times the Earth's mass and 10 times the Earth's radius.

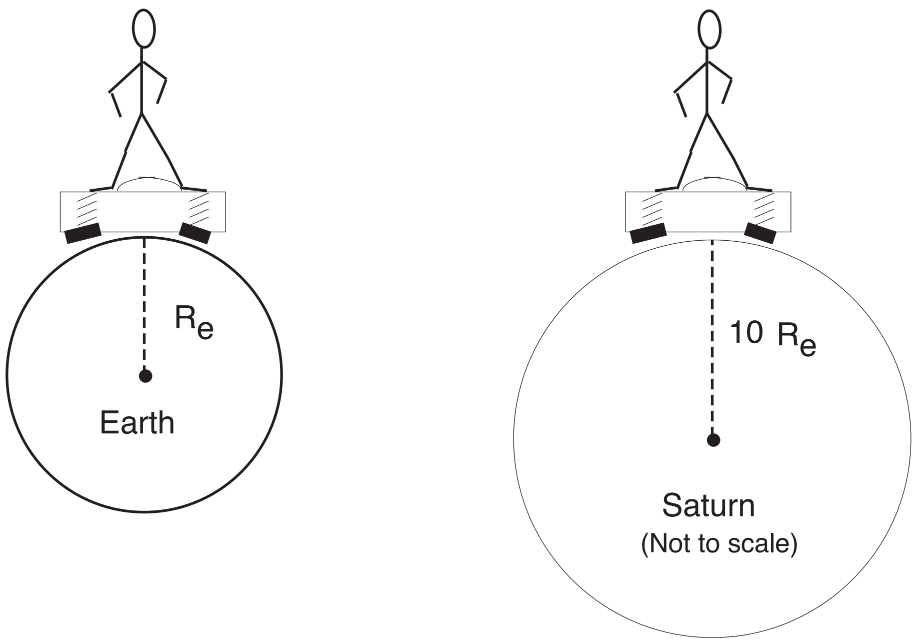


Figure 6.17

a.) By what ratio does the number of masslets in the student change on Saturn compared to the Earth?

____________________________.

b.) By what ratio does the gravitational force (weight) on Saturn compare to the weight on the Earth?

____________________________.

3.) A dump truck is parked next to a candy bar. A person walks by and takes a bite out of the candy bar and places the remainder of the bar back in the same spot. Compare the gravitational force the dump truck exerts on the candy bar before and after the bite is taken out of the bar. Which is larger, or are these forces the same size? Explain.

4.) A big feather that weighs about one Newton (.1 kg mass) is dropped from a high cliff and gently floats down toward the Earth.

a.) How much force does the Earth experience as the feather pulls up on the Earth?

____

b.) Does the Earth really feel a force when air friction has such an important part in the problem? (Note: the air friction is equal to about 1 N of force.)

5.) Considering the problem of the truck and the water bottle in Figure 6.18 answer the following:

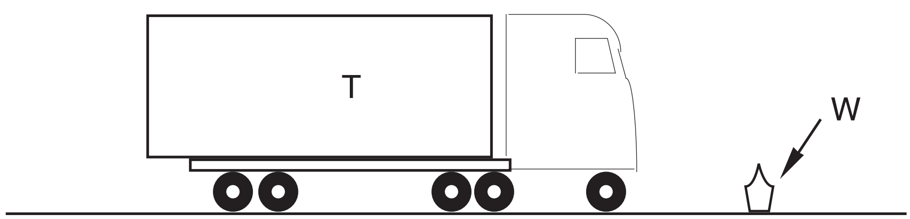


Figure 6.18

a.) By what ratio would the gravitational force between them change if the mass of the truck were doubled and the mass of the water bottle were five times as large?

b.) By what ratio would the gravitational force between the two objects change if *both* masses were doubled and the distances between their centers were doubled?

c.) By what ratio would the gravitational force change if the distance between the objects' centers were reduced to half the original distance?

UNIT 7

Inertia

UNIT #7 - INERTIA

I. OVERVIEW OF THE INERTIA UNIT

A. MAJOR PRECONCEPTIONS POSING DIFFICULTIES IN THIS UNIT

1.) Friction and gravity are the primary factors responsible for an object's tendency to resist speeding up from rest.

2.) A large mass is much easier to stop than to start under low friction conditions.

3.) A constant net force causes a constant velocity.

B. GENERAL STRATEGY OF THIS UNIT

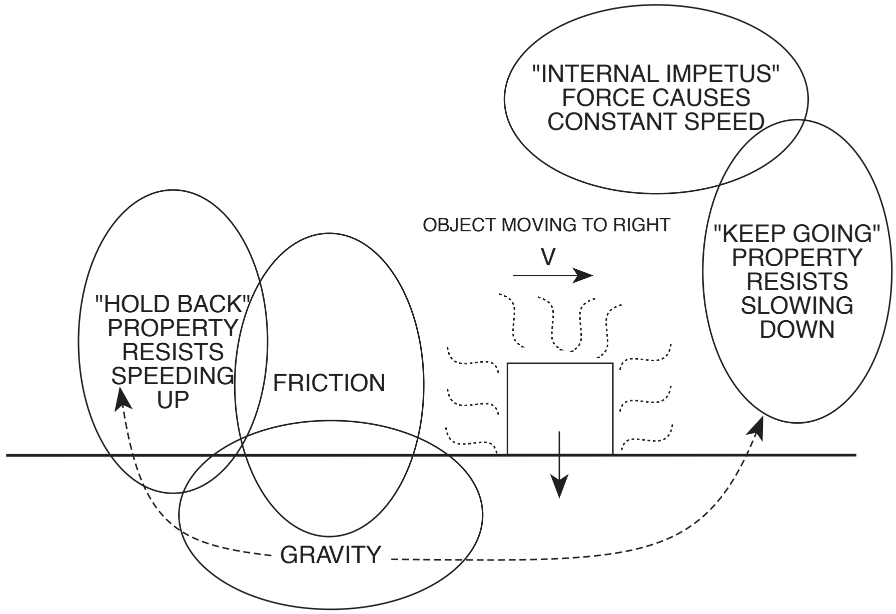
This unit begins with a pre-quiz to start students reflecting about why it is hard to increase or decrease the speed of an object.

Students then participate in a class demonstration, in which some students speed up and slow down other students on a skateboard, hovercraft or lab cart. The purposes of the demonstration are to:

1.) Give students some kinesthetic experience with the fact that a constant force produces accelerated, not uniform motion, and that more force is required to increase the speed of a more massive object.

2.) Provide experiences that can be discussed and explained in extended discussions. The struggle to make sense of the observations made in the demonstration is more important than making measurements.

C. **CONCEPT DIAGRAMS**

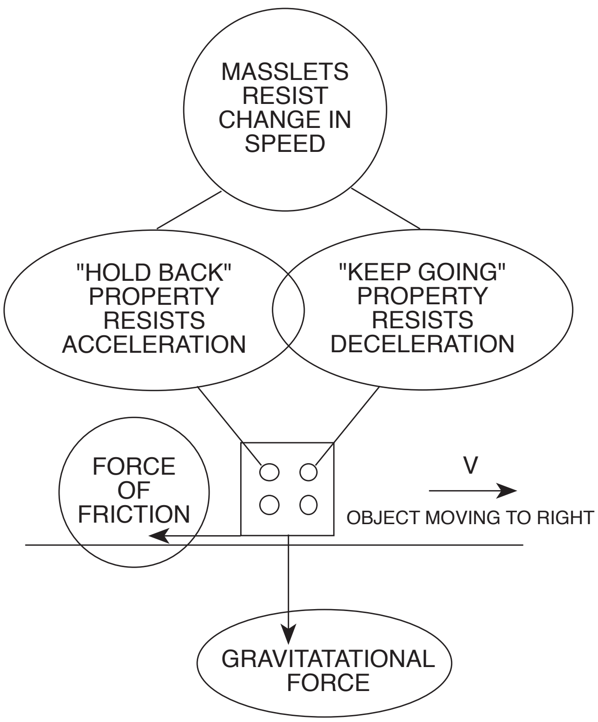


NAIVE CONCEPTS

Figure 7.1

The concept of inertia can be badly confounded with concepts of friction and gravity, as displayed in Figure 7.1, which shows how these concepts are intertwined in the mind of the naive learner. The block in the figure can be thought of as a massive crate being pushed on rough ice with first an accelerating force, and then later, an opposing force. In both cases, the block is sliding to the right on a surface with some friction. When the crate is being accelerated to the right with a constant applied force, students believe that the massive crate resists being accelerated instantaneously. However, in talking about the source of this resistance, students do not distinguish well between friction, gravity, and the "hold back" effect of inertia (resistance to increasing speed.) The overlapping circles on the left in Figure 7.1 represent these confounded concepts.

Once the block is moving over the ice with considerable speed, one can apply an opposing force to decelerate it. Students again believe that the crate cannot be slowed instantaneously, but they tend to confound the "keep going" side of inertia (resistance to being decelerated) with the common preconception of an internal force that keeps the block moving. The wavy lines around the block represent a naive conception of friction as a directionless retarding influence rather than a well defined force with a definite direction. We recommend that teachers seriously consider the difficult task involved in sorting out the overlapping concepts and preconceptions of Figure 7.1 into the separate and well distinguished concepts shown in Figure 7.2. In view of that, this unit is designed to lead students to a clearer understanding of inertia as a property of mass that is a separate concept from the concept of force.



INTERMEDIATE CONCEPTS

Figure 7.2

Initially, the lessons treat the inertia concept in two pieces, using the temporary simplified concepts of: (1) a "hold back" property of mass, defined as the inherent resistance of mass to having its speed increased by a force. (2) a "keep going" property of mass, defined as the inherent resistance of mass to having its speed decreased by a force. Helping students separate the "hold back" aspect of inertia from gravitational and frictional *forces,* as shown in Figures 7.1 and 7.2 is a major objective of this unit. Later, the temporary concepts "hold back" and "keep going" can be combined to form the single inherent property of mass physicists call inertia.

The main objective here is to begin with vocabulary that is easy enough for students to use fluently so that it will tap useful intuitions and encourage discussion and thinking rather than memorization. Even students who have been introduced to the concepts of positive and negative acceleration will spontaneously tend to make a natural distinction between these "two types" of inertia. In order to make sense of the idea that they can be seen as the same property, we must give each "type" a name, get the names into the discussion so that everyone knows what we are talking about, and *then* make a point of arguing that they are the same property. This strategy deals systematically with the students' preconceptions, whereas simply announcing immediately that "inertial mass resists (positive or negative) acceleration" is too abstract as an introduction and can lead to rote memorization without understanding.

Prerequisites. This unit is planned based on the assumption that students have been exposed to earlier work on friction forces and gravitational forces. Since these two concepts are entangled with inertia for many students, some introductory work on friction and gravity such as Unit 3 and Unit 5 is strongly recommended as a prerequisite. Prior work should include the idea that a force is exerted by one object acting on another object, not within a single object.

D. **THE PHYSICIST'S VIEW**

The inertial behavior of mass is a very difficult concept for most students to grasp for several reasons. Students often come to class with naive preconceptions about the cause of gravity. In addition, they have notions of gravitational force and inertia as interconnected. Inertia is also difficult to separate from friction and students often confuse the two, think they are the same, or believe one causes the other. Finally, students have had little experience with a zero friction environment so it is difficult for them to imagine how an object would behave in one.

Some physicists may be uncomfortable with language in this unit which suggests that inertia is an internal property of an object. We feel it is helpful to make a significant effort to help students separate the inertia concept from the notion of forces which are caused by interactions with outside agents. Therefore, we recommend that teachers strongly consider suggesting to students that they think of inertia as an internal or intrinsic property of a unit of mass.

This unit is designed to move students from the concepts represented in Figure 7.1 to those in Figure 7.2, and from there to a single, integrated concept of inertia. We have observed that students have some very useful intuitions about inertia--about massive objects being difficult to accelerate or decelerate. We can and should build on these useful intuitions. There are two problems however. First, these intuitions about inertia can be confused with ideas about friction and gravity very easily. Second, students tend to think about acceleration and deceleration as separate cases, and to think about "hold back" and "keeps going" properties of inertia separately. Thus, Figure 7.2 represents the use of concepts at a natural intermediate level somewhere between the concepts of the naive student and the expert. We have found these to be a useful stepping stone in instruction. While these diagrams are not necessarily offered for sharing with students, it is helpful for teachers to recognize stages that many students must move through in order to begin to grasp the fundamental nature of the inertia concept as separate from gravitational and frictional forces (Figure 7.2).

It is important for teachers to help students construct the following ideas during the lessons:

1.) Mass resists being accelerated or decelerated. The more mass (inertia) an object has, the greater the resistance to a change in speed. (We do not deal here with resistance to changes in direction. This can be taught after the concepts in this unit have been mastered.)

2.) Inertia is not a force, but a permanent, intrinsic property of mass.

3.) Weight is a gravitational force and may cause more friction, giving the false impression that weight or gravity is responsible for inertia rather than mass. Friction is a force that can oppose motion but is not related to inertia. The Earth's gravity is often one of the forces that brings moving surfaces together to cause friction. But ideas about gravitational forces and inertia must also be separated conceptually. They play very different roles as different parts of an explanation for why it is difficult to accelerate an object sliding on a surface.

4.) In a frictionless situation, the amount of force required to start an object moving is the same amount of force required to stop the object in the same amount of time.

In addition to the vocabulary and verbal principles learned, the imagery students develop is extremely important. The recommended imagery for the intermediate concept of the "keep going" property of mass is that of the intrinsic resistance of the mass in a "coasting" (frictionless) object to being quickly decelerated by an opposing external force. This resistance is not itself a force, but it prevents the velocity from changing instantaneously--it takes time for an external force to change velocity, and the greater the mass, the greater amount of time it takes for a given force. Similarly, the imagery for the "hold back" property is an intrinsic resistance of the mass in an initially coasting object to being accelerated by an external force. These inertial properties must be separated from the imagery for forces. For example, "hold back" must be separated from frictional and gravitational forces; and the "keep going" property must be separated from the naive preconception of an internal (historically, "impetus") force that keeps the object moving at a constant speed. After these separations have been accomplished, the "keep going" and "hold back" properties can be combined into the single concept of inertial mass, as the image of intrinsic resistance of mass to any type of change in velocity.

According to science historians, it took Isaac Newton years to work out some of these same qualitative distinctions prior to developing his final theory. Therefore, we should expect to need a considerable period of time in order to foster conceptual reorganizations in students.

II. INERTIA – LESSON 1

A. OVERVIEW OF THE LESSON

The Pre-Quiz is the central device in this lesson designed to start students thinking about why it is hard to speed things up or slow things down.

The demonstrations with a skateboard, low friction cart of some sort, or hovercraft are valuable to start students thinking about the difficulty of maintaining a constant force acting on an accelerating object. It also becomes clear in this demonstration that the hold back property is dependent on mass.

The final set of demonstrations with a small dynamics cart on a table, offers three important examples for student discussion.

It should be noted that the use of *hold back* and *keep going* terminology are recommended throughout this lesson. The inertia terminology is introduced in the next lesson.

B. MATERIALS

1.) Pre-Quiz - Inertia I sheets

2.) Equipment for the Skateboard / Lab Cart / Hovercraft (available from PASCO) Demonstration

3.) Flat top dynamics cart with open ends and a lacrosse ball.

4.) Homework sheets - Inertia I - Day #1

C. OBJECTIVES

1.) The student should be able to identify the variables that affect the difficulty of speeding up an object or slowing down an object.

2.) The student should be able to recognize the difficulty encountered by a person trying to apply a steady force on an accelerating object.

3.) The student should be able to site a clear and simple example showing more mass has greater "keep going property."

4.) The student should be able to describe a number of situations illustrating the "hold back property."

D. **LESSON PLAN - INERTIA - DAY #1**

1.) Administer the Pre-Quiz[1].

2.) Discussion of the Pre-Quiz (short)

Discuss the following question related to the Pre-Quiz. At this point, it is not necessary to reach resolution on these questions. Paraphrase students' arguments and introduce suggested terminology (friction force, gravitational force, "hold back property", "keep going property", etc.) as ideas are genreated by students.

• What is really responsible for an object's tendency to resist change in motion? (Draw out as many factors as possible.)

3.) The Skateboard / Lab Cart / Hovercraft Demonstration[2]

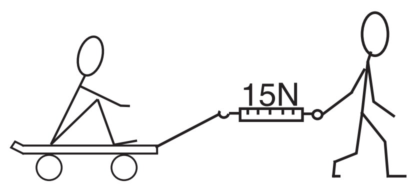


Figure 7.3

a.) Locate a corridor or some other large space. Ask one volunteer (light) student to sit on the skateboard/cart and secure a loop of cord to the cart and to the spring scale.

b.) A second student will pull on the spring scale with a steady 15N force (perhaps more). Hold a foot in front of the cart until the puller has established the desired force. The puller then is instructed to keep the force constant as long as possible. Probably 2 trials are desirable as the first run is practice.

c.) Ask the puller, "Why was it hard to keep the scale reading constant?"

d.) Select a third volunteer student, of significantly larger mass, to ride on the cart and ask a fourth student to repeat the pulling process using the same force.

e.) Ask the class to comment on differences between the two demonstrations.

---

[1] Encourage students to do their best, but tell them the quiz does not count on their grade. Students who have difficulty should be advised that this introductory material will gradually become clear.

[2] Those teachers who would prefer to use this activity as a lab for the whole class will find the lab sheets with other Materials for Duplication.

4.) Demonstrations with a ball and a flat top dynamics cart

a.) A smooth flat top dynamics cart with open ends is needed. Two carts attached with a board on top would work well.

b.) Public Vote Question:

"Does a steel ball on a smooth table in a bus or train traveling at a constant velocity need a force to keep it moving?"
"Is a force needed to keep it in the same location on the table?"

c.) Constant velocity Demonstration 1 (keep going property)

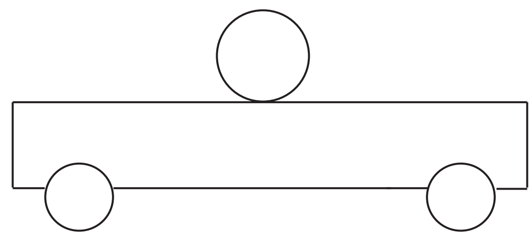


Figure 7.4

With the ball in the center of the cart, hold your hand on the ball and the cart as you start it moving. When you release your hand the ball and cart should continue at a steady speed with the ball staying in the middle.

Discuss the result and repeat as needed.

d.) Acceleration Demonstration 2 (hold back property)

With the ball in the center of the resting cart, place a piece of tape on the table edge to mark the ball's initial location. Next, jerk the cart quickly forward, and note that the ball lands very near the starting point.

Discuss forces acting on the ball.

e.) Deceleration Demonstration 3 (keep going property)

Start the cart moving with the ball in the middle as in the constant velocity case above. This time, arrange a collision so the cart stops instantly and the ball keeps going.

Ask the class "Did the ball keep going at the same speed?"

Perhaps the demonstration can be repeated blocking off the view of the cart with cardboard so the class can only see the constant speed of the ball during the collision.

Once again ask about forces acting on the ball.

f.) If time allows, perform one or two more demonstrations that illustrate the keep going and hold back properties. (see <u>TEACHING NOTES - DAY #1</u> below).

5.) <u>Homework assignment Inertia I Day #1</u>

E. **TEACHING NOTES - INERTIA - DAY #1**

An open discussion of the Pre-Quiz with the suggested questions should be stimulating. It may be possible to help students clarify the roles of gravitational and friction forces to some degree at this early stage in the unit.

The ball on the cart demonstrations illustrate both the "keep going" and the "hold back" properties and they are strongly recommended. These additional demonstrations may be helpful:

- Pull a piece of paper from under a beaker
- Pull a table cloth from under some tableware
- Ball shoots straight up and falls back into a moving inertia cart

Practice your demonstrations first!

These demonstrations are often explained using *Newton's first law* (that an object at rest or moving at a constant velocity will remain in that state in the absence of an unbalanced external force). Research has shown that the simple memorization of Newton’s first law, (The Law of Inertia), is of little practical value unless a student has been given the opportunity to struggle with the inertia concept in a variety of situations. Students should be confronted with the inertial behavior of matter in:

Constant velocity situations, *keep going property*
Acceleration situations when the *hold back property* is evident
Deceleration situations when the *keep going property* is evident

III. INERTIA LESSON - DAY #2

A. OVERVIEW OF THE LESSON

The lesson begins with a homework review of student generated examples illustrating the "hold back property" and "keep going property". At the end of the homework discussion, it is recommended that the teacher formally introduce the term inertia for the first time.

Next, the Skateboard Explanation Worksheet #1provides small group work to help students separate the external forces of gravity and friction from the internal property of inertia. After some class discussion, a demonstration with the inertial balance is designed to show that the "hold back" and "keep going" intrinsic properties produce slower behavior as mass is added to the low friction inertial balance. Skateboard Explanation Answer Sheet #1 is studied by the students and discussed.

Then the influence of the gravitational force on the inertial balance is tested in a demonstration when the mass is suspended from a string to cancel the effect of the gravitational force. Following the discussion of the experiment, the Skateboard Explanation Answer Sheet #2 is passed out and discussed.

The summary discussion then emphasizes the fact that the inertial property of mass is independent of the external gravitational and frictional forces.

B. MATERIALS

1.) Skateboard Explanation Worksheet #1 and Answer Sheet #1

2.) Skateboard Explanation Worksheet #2 and Answer Sheet #2

3.) Inertial balance apparatus with 2 masses

4.) "C" clamp

5.) string to suspend mass from ceiling or tall ring stand (1 meter)

6.) pair of wire brushes (friction demonstration review)

7.) Homework Sheets Inertia Day #2

C. OBJECTIVES

1.) Students will be able to articulate their intuitions about "hold back property" and "keep going property" to describe the internal property of an object called inertia.

2.) Students will begin to distinguish between the friction force acting on an object and the "hold back" property of mass.

3.) Students will begin to understand the difference between the inertial properties of matter and forces that act on an object.

4.) Students should be able to demonstrate that they believe the gravitational force and inertia are separate concepts and that inertia is not caused or partly caused by the gravitational force.

5.) The student will understand that "hold back property" equals "keep going property"; thus we may combine these two ideas as the "inertia" concept.

6.) The student should be able to visualize mass in standard units (masslets) that each have *internal* "hold back" and "keep going" properties.

7.) The student will understand that inertia is an internal (intrinsic) property of each "masslet" and that it is fundamentally different from external forces that act on a "masslet".

D. LESSON PLAN - INERTIA – LESSON 2

1.) Discuss homework and review terms

a.) Discuss the homework. Review the terms below using a *diagram* (Figure 7.1) that illustrates them. We have observed students introducing the following ideas:

• "Hold back property" = resistance to speeding up (of mass)
• "Hold down tendency" = tendency to be held down in place (label gravitational force if preferred)
• Friction (throughout this unit one needs to remind students that this is a force with a definite direction that opposes the motion)
• "Keep going property" = resistance to slowing down of mass, (may or may not be discussed)

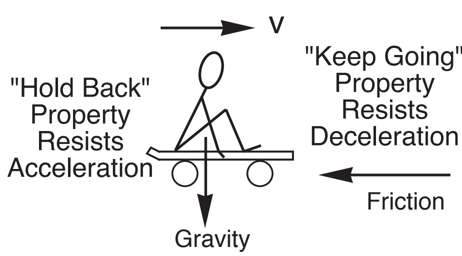


Figure 7.5

b.) Explain that these terms ("keep going property", "hold back property" and "hold down tendency") were used in the class *temporarily* to strengthen your intuitive ideas about factors affecting motion.

c.) Now we will replace "hold back" and "keep going" properties with the term ***inertia***.

d.) Remind the class *not* to refer to "hold back and keep going" properties of inertia as forces, since they are the inertial property of mass. This property seems to be within each piece of mass. Forces, however, are actions that are caused by external objects. Students will often confuse inertia with friction forces. Therefore, students need to be reminded that friction is an external force independent of inertia.

2.) Pairs or small groups work on the (Skateboard Explanation Worksheets #1 and #2)[3]

Question #1 is: "Why does a skateboard eventually stop after it has been coasting?"
Question #2 is: "What is the main reason the more massive skateboard would be harder to stop?"

Students are asked to break into pairs or small groups and to:

a.) Discuss and fill out Skateboard Explanation Worksheets #1 and #2 (suggested time 10-15 minutes).

b.) Remind them to keep in mind the question on top of the sheet.

3.) Reconvene the class

Wrap up this part of the activity allowing students to share any urgent comments about the Skateboard Worksheets.

The teacher should refrain from sorting out any confusion at this point by assuring the class that more clarity will come during the demonstrations to follow.

4.) Demonstrate the inertial balance (Low friction experiment)

a.) Set up an inertial balance (Figure 7.6) without any added mass. Demonstrate that the balance does not apreciably decrease in amplitude, as evidence that it is a low friction device. (If some students seem unconvinced, the device could be set in motion while completely laying on a table to show how quickly friction brings it to rest.)

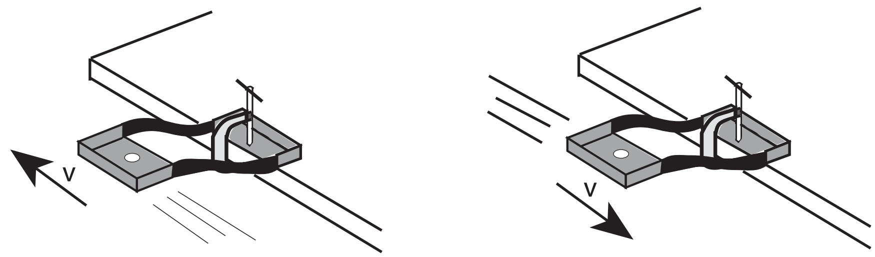
b.) Take a *public vote* on the question:

Will added mass make this low friction device vibrate at a faster frequency, a slower frequency, or the same frequency?

c.) During the discussion of the vote remind students that friction should still be a minor factor even with more mass on the platform.

d.) Using your hand, move the inertial balance slowly through 1/2 cycle, showing where the mass is exhibiting its "keep going" property and where the mass is being "held back".

[3] The teacher may find the need to initiate discussion of the first question in large group discussion so that students learn how to focus on the words used in this kind of activity sheet.



"Keeps going" resists slowing down while going from the center to the left.

"Hold back" resists speeding up while going from the left end to the center.

Figure 7.6

e.) Demonstrate the balance again with added mass attached, (not suspended). Discuss the new slower behavior *and ask whether it is due to increased friction or something else*.

f.) Help draw out the conclusion that the added mass slowed the balance considerably and this is due to the increase of either the "hold back part of the inertia property" *or* the increased gravitational force, but *not to increased friction.* (We will deal with the gravity question later.)

5.) Large group discussion of Skateboard Explanation Worksheet #1

a.) For each explanation on Worksheet #1 ask for a show of hands and tally the classes responses. "How many have a makes sense rating of 3 or higher on each explanation?" Tabulate the results.

(a)________ (b)________ (c) ________ (d) ________

b.) Discuss each explanation by asking someone for whom the explanation made some sense to say how it made sense. Encourage discussion by remaining neutral at this point. A carefully labeled diagram (see Figure 7.5) on the board could be helpful in focusing the discussion. Teacher's paraphrasing and clarification of students' views, using the diagram, will aid students in focusing on each other's comments.

6.) Development of a masslet model

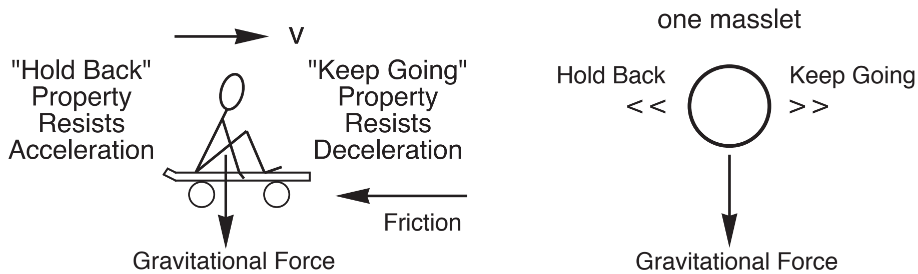


Figure 7.7

Using the masslet diagram above, review the *masslet model* as introduced in the gravitational force lesson. Emphasize the fact that this model also includes the inertial property of mass.[4] Each masslet experiences a gravitational force and has "hold back" and "keep going" properties.

7.) Discussion of Skateboard Explanation Answer Sheet #1

a.) Toward the end of the discussion hand-out the Skateboard Explanation Answer Sheet #1 and give the class time to read it and record their makes sense scores.

b.) Ask for people who think the physicist's explanation makes less sense than the others to express their qualms. Ask other students who believe it makes sense to explain it. The teacher should at this point be adding his/her clearest statements of the physicist's point of view.

c.) Illustrate parts c) and d) of the Skateboard Explanation Diagram #1 by using the "brush model"[5] for friction. It may be helpful to demonstrate with the wire brushes.

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[4] The "masslet model" is used to refer to the idea that one may imagine mass as composed of small, standard units called "masslets". The "masslets" concept is used extensively in the Gravity II unit.
[5] See Friction Unit 3 for the presentation of the brush model.

8.) Demonstration of inertial balance with mass suspended on a string to cancel the gravitational force.

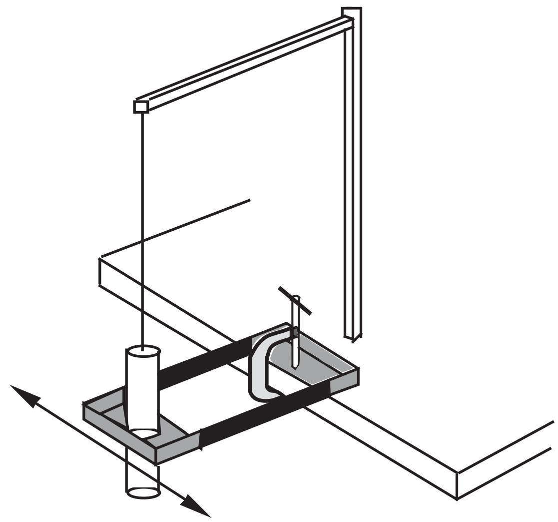


Figure 7.8

a.) Ask the class "Does the gravitational force (hold down force) affect the behavior of this device?" Following comments from students, the teacher should emphasize the fact that we need to eliminate the gravitational force from this experiment.

b.) Add a mass that is not suspended from the ceiling and ask if the device would vibrate faster or slower in outer space where gravitational forces are tiny.

c.) Then time 20 vibrations of the inertial balance. This probably works best with the teacher counting out loud and 2 or 3 students timing with stop watches.

d.) *Public vote*: Ask students: "Will the inertial balance move slower, faster, or at the same rate if we could cancel out the gravitational force with the mass suspended to balance the gravitational force so the platform does not need to support the mass while it is vibrating?"

e.) Set up the new experiment with the mass suspended from a long string going to the ceiling. Then lead the class to agree that timing within 0.4 sec would be equal given the possible errors. Finally, time 20 cycles with the mass suspended and show the results are the same given our expected error.[6]

f.) Conclude from the nearly equal times that gravitational force is not necessary for the existance of the "hold back" and "keep going" properties of inertia. This experiment also suggests that the inertia

[6] Hold a piece of paper at the release point so that the balance hits it and makes a noise; this makes it easy for the class to count the cycles.

property would still exist in outer space where there is no significant gravitational force. Some students may object to this simulation of outer space conditions. In this case, the teacher should respectfully acknowledge that those students have a fair complaint, but in reality the results would be the same.

9.) Students complete the Skateboard Explanation Answer Sheet 2

a.) Review the question: What is the main reason the more massive skateboard is harder to stop?

b.) Have all students review the explanations and indicate a makes sense score for each case.

c.) When all have completed the task, ask for a show of hands and tally the group's opinions: How many have a make sense rating of 3 or higher on each explanation?

(a) __?__ (b) __?__ (c) __?__

d.) Review each explanation on the sheet. Ask for someone for whom each explanation made some sense to say how it made sense. Encourage discussion by drawing out student's ideas.

e.) After some discussion, ask for people who think the physicist's explanation makes less sense than the other explanation to express their qualms. Then ask students for whom the physicist's explanation makes good sense to explain it.

f.) In stating the physicist's position, emphasize the internal or intrinsic nature of the "inertial" property of matter (as opposed to externally imposed friction forces).

10.) Summary statement for the lesson

We have tried to demonstrate today that "hold back" and "keep going" are *internal* properties of mass that are distinct from friction and gravity. Friction and gravity are *external forces* which can act on a mass, but they are separate from the inertial properties of each piece of mass.

11.) Collect homework if desired

Collect Homework Day #1.

12.) Assign homework

a.) Homework Inertia - Day #2

E. <u>TEACHING NOTES - INERTIA - DAY #2</u>

The early part of this lesson needs to move along quickly in order to allow time for the very important issues at the end. The student sharing from the homework section should go quickly with only a brief discussion after all have shared their ideas. Then, the small group work on Skateboard Explanation Diagrams #1 and #2 should be held to 10-15 minutes even if some groups have failed to reach consensus on that task.

The first vote on the inertial balance is primarily designed to focus student attention on the balance, which is probably new to them. The initial demonstration should help them understand that *friction is not the major factor* that slows the vibration when the mass is increased. However, the class needs to recognize that gravitational force, "hold back", and "keep going" are still under consideration.

When the first demonstration is done the teacher may add mass to the platform by attaching a couple of "C" clamps or taping on about 1/2 kg of mass. The matter of suspending (not attaching the mass) is vital in the later demonstration where we wish to show that *gravitational force* does not slow down this device.

When reviewing the answers to Skateboard Explanation Answer Sheet 1, students should be encouraged to offer views about why each response makes sense. The presentation of the answer sheet should make the teacher’s position clear. From this point on the teacher should emphasize the notion that "hold back" and "keep going" are intrinsic, permanent properties of mass that are very different from forces.

Even though some students may not be able to articulate their idea that "hold back" is caused by gravity, the teacher is reminded that the second demonstration is very important as an aid to many students. You should practice timing 20 vibrations of the inertial balance both with and without the supporting string. A couple of students with stopwatches will usually yield an average result that is within .3 seconds for the two cases. *Be sure the result is emphasized* and that students appreciate the fact that the second set up simulates zero gravity, thus indicating that gravity is not the cause of the "hold back" and "keep going" properties.

Teachers with MBL equipment such as sonic rangers could arrange to time the inertial balance vibrations with that equipment. This demonstration would only seem appopriate if students have had earlier experience with the sonic ranger.

IV. MATERIALS FOR DUPLICATION

A. PRE-QUIZ INERTIA

B. HOMEWORK

1.) Inertia - Day #1
2.) Inertia - Day #2

C. EXPLANATION DIAGRAMS

1.) Skateboard Explanation Worksheet #1
2.) Answer Sheet #1
3.) Skateboard Explanation Worksheet #2
4.) Answer Sheet #2

D. LAB. ACTIVITY SHEETS

1.) Skateboard Lab. - Activity #1 (optional)

E. QUIZ AND TEST QUESTIONS - INERTIA

PRE-QUIZ - INERTIA

Name: ____________________

Period: ____Date: ___________

The following questions apply to one person pulling another person sitting on a skateboard that has minimal friction. Select the best answer to each question.

1.) Sarah pulls Jim from rest with a *steady force* of 15 N for ten seconds. During this time how would you describe Jim's motion?

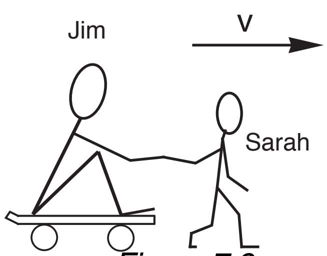


Figure 7.9

a.) Jim will travel at a constant speed.
b.) Jim will keep speeding up.
c.) Jim will speed up and then move at a constant speed.
d.) Other (fill in).

____

2.) Sarah and Jim switch places so that Jim is pulling Sarah on the skateboard. Jim happens to be much more massive than Sarah. In fact, Jim is at least twice as massive as Sarah. Jim pulls with the *same constant 15 N force* for the *same period of ten seconds.* How fast is Sarah moving at the end of the ten second period?

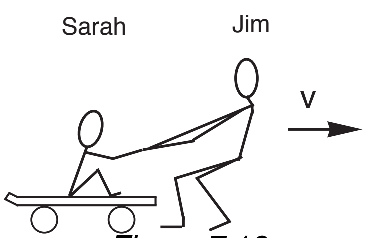


Figure 7.10

a.) Sarah will have reached a higher speed than Jim did in problem 1.
b.) Sarah will have reached the same speed that Jim did in problem 1.
c.) Sarah will have reached a lower speed than Jim did in problem 1.
d.) Other (fill in).

____

3.) After Jim pulls Sarah for ten seconds he quickly moves behind her and tries to slow her down by using a steady 15 N force. How much time will it take to stop Sarah?

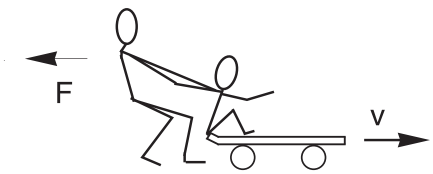


Figure 7.11

a.) Sarah will come to a stop after more than ten seconds.
b.) Sarah will come to a stop in about eight to ten seconds.
c.) Sarah will come to a stop in less than four seconds.
d.) Other (fill in).

____

4.) Heavy Jim and light Sarah switch again. This time Sarah pulls Jim so he reaches the same top speed that she reached in question 3. Then, Sarah runs behind him to try to stop him from moving using only a steady 15 N force. How much time will it take to stop Jim?

a.) Jim will come to a stop in the same amount of time it took to stop Sarah.
b.) Jim will take a longer time to stop than Sarah did.
c.) Jim will come a stop in less time than Sarah did.
d.) Other (fill in). ________________________________

HOMEWORK - INERTIA - DAY #1

Name: ____________________

Period: _____Date: ___________

1.) List as many reasons as you can that a physicist might give to explain why it is harder to start a more massive person moving on a skateboard than a less massive person.

2.) Think of an example that you could use to convince a friend that an object at rest has an "internal hold back property" that is different from a frictional force or the force of the Earth's gravity. Explain or diagram your example.

3.) Think of an example that could convince a "non-physics" friend that a moving mass has an internal "keep going property" that does not depend on outside forces. Explain or diagram your example.

4.) Suppose you were riding a bicycle at 10 mph on a smooth flat road.

a.) If you stop pedaling, what happens to your motion?

b.) List as many causes as you can (in order of importance) for why your motion changes.

HOMEWORK - INERTIA - DAY #2

Name: ____________________

Period: _____Date: __________

1.) Predict below the results you would obtain on the *Skateboard / Lab Cart demonstration* if you did the activity in a completely frictionless environment with *no surface friction, rolling friction, or air friction.*

Keep in mind the results of the inertial balance demonstration done in class where friction was quite small but still present: 1.) the motion lasts a long time; 2.) increasing the mass slows down the motion; 3.) the motion stays the same if one removes the effect of gravitational force by supporting the mass with a string attached to the ceiling.

I.) While being pulled with a constant 15 N force, Sarah (the rider) will:

a.) Travel at a constant speed
b.) Keep speeding up at a constant acceleration
c.) Speed up at first and then move at a constant speed

II.) What will happen to the motion above if the mass of the rider is larger?

a.) Smaller constant speed
b.) Greater constant speed
c.) Greater acceleration
d.) Smaller acceleration

III.) If Sarah is accelerated for only three seconds to a speed of 1 m/sec and then allowed to continue on her own.

a.) How far will she travel? Can you predict?

b.) What variables affect how far she will travel?

2.) How do the effects of a starting force and a stopping force compare? We pull Sarah for ten seconds with 15 N during which she goes nine meters. We then move behind and pull back with 15 N.

a.) How far will she travel after the force direction is changed? Why?

b.) How much time will it take to slow her down to a stop? Why?

3.) If we push Sarah and Harry (Sarah has more mass) on two skateboards so they are lined up going at the *same speed* and then try to stop each one with a 15 N force, who will stop first? Why?

INERTIA
SKATEBOARD EXPLANATION WORKSHEET #1

Name: ____________________Period________Date_______

QUESTION 1: WHY DOES A SKATEBOARD STOP AFTER A WHILE WHEN COASTING WITH NO ONE PUSHING OR PULLING?

Your group should chose a makes sense score for each of the four explanations below. Use the numerical scale from 1 to 5 for your answers.

1	2	3	4	5
Makes no sense to me	Makes only a little sense to me	Makes some sense to me	Makes quite a bit of sense to me	Makes perfect sense to me

Explanations:

a.) Directionless resistance of friction. The skateboard stops because friction is everywhere, providing resistance, but not exerting a force in any particular direction.

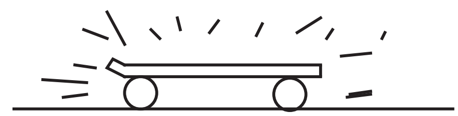


Figure 7.12

Sense score ____

Briefly say why this explanation does or does not make sense.

b.) Objects always seek a state of rest. The skateboard stops because objects stop when there is no net force to keep them going. Rest is the natural state for any object.

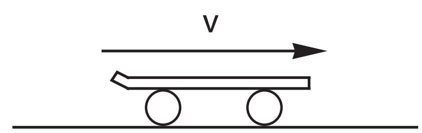


Figure 7.13

Sense score ____

Say Why.

c.) "Hold down tendency" (gravitational force). The skateboard stops because gravitational force is pulling down on the object, "holding it down."

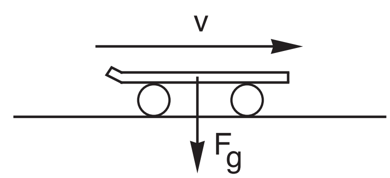


Figure 7.14

Sense score ____

Say Why.

d.) Force of friction in direction opposing motion. The skateboard stops because there is a frictional force from the floor (and a small amount from the air) exerted in a definite direction to the left.

Sense score ____

Say Why.

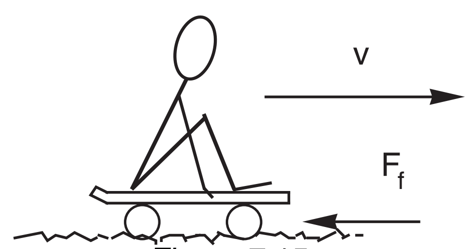


Figure 7.15

QUESTION 2: EVEN THOUGH ALL OF THESE EXPLANATIONS MAKE SENSE TO MANY PEOPLE, ONLY ONE OF THESE ARGUMENTS STATES THE PHYSICIST'S VIEW. WHICH ONE? CHECK CAREFULLY.

EXPLAIN WHY.

INERTIA
SKATEBOARD EXPLANATION - ANSWER SHEET #1

QUESTION 1: WHY DOES A SKATEBOARD STOP AFTER A WHILE WHEN COASTING WITH NO ONE PUSHING OR PULLING?

a.) Directionless resistance of friction. Friction is everywhere, providing resistance, but not exerting a force in any particular direction. Physicist's view: (We found in an earlier lesson that the frictional force on the skateboard pushes horizontally to the left, therefore it is not "directionless").

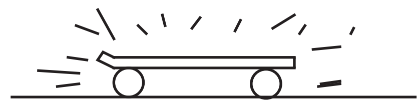


Figure 7.16

b.) Objects always seek a state of rest. Objects stop when there is no net force to keep them going. Rest is the natural state for any object. Physicist's view: (This may seem true, but in these cases it is invisible frictional forces that stop things. Also, the motion of planets and objects on air tables shows us that when there is no friction, motion at a constant velocity is just as natural as rest).

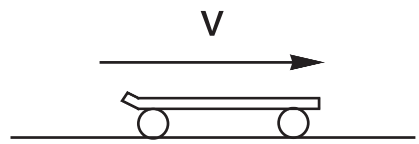


Figure 7.17

c.) "Hold down tendency" (gravity). Gravity is pulling down on the object, "holding it down." Physicist's view: (Gravitational force causes stopping only indirectly since without it to hold the skateboard against the floor there would be no friction. But the gravitational force is not the direct cause of deceleration, since it points in the wrong direction -- down instead of back. Besides, the gravitational force is exactly canceled by the upward force of the floor).

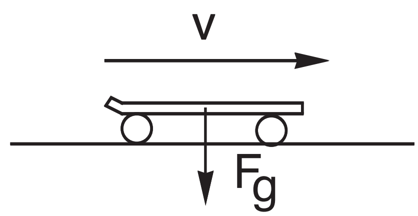


Figure 7.18

d.) **Physicist's explanation: force of friction in the direction opposing motion**. A friction force from the floor exerted to the left provides an unbalanced force that decelerates the object. If there were no friction, the object would not slow down! (As is true in space.)

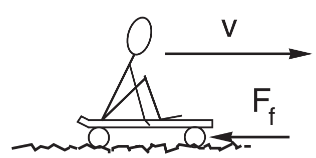


Figure 7.19

INERTIA
SKATEBOARD EXPLANATION WORKSHEET #2

Name: ____________________Period: _____ Date: __________

Imagine trying to stop a moving skateboard with a 15 N force. If this is done using a very good, low friction skateboard, a more massive skateboarder will be harder to stop than a less massive skateboarder.

QUESTION 1: WHAT IS THE MAIN REASON THE MORE MASSIVE SKATEBOARD WOULD BE HARDER TO STOP?

Choose a makes sense score for each of the three arguments below. Note: The skateboard is moving to the right and the person is pulling to the left.

1	2	3	4	5
Makes <u>no</u> sense to me	Makes <u>only a little</u> sense to me	Makes <u>some</u> sense to me	Makes <u>quite a bit</u> of sense to me	Makes <u>perfect</u> sense to me

<u>Explanations:</u>

a.) <u>More mass means more friction</u>. The skateboard would be harder to stop because more mass in an object causes greater outside friction forces that make it harder to stop. Sense score ______

Briefly say why this explanation does or does not make sense.

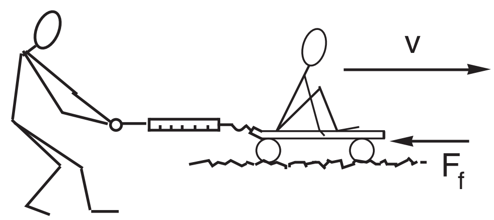


Figure 7.20

b.) <u>Greater "hold down tendency" (gravitational force)</u>. The skateboard would be harder to stop because more mass means more "hold down tendency" or downward gravitational force causing the object to slow down.

Sense score _____

Say why.

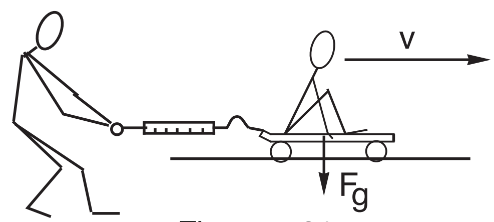


Figure 7.21

c.) <u>"Keep going property" of mass</u>.
The skateboard would be harder to stop because each masslet resists decreasing speed (the "keep going property" of mass). Therefore more masslets mean more resistance to being slowed down.

Sense score _____

Say why.

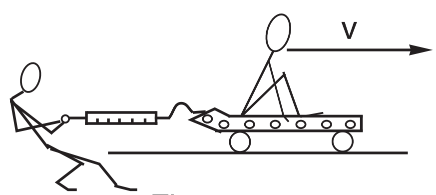


Figure 7.22

<u>QUESTION 2: EVEN THOUGH ALL OF THESE EXPLANATIONS MAKE SENSE TO MANY PEOPLE, ONLY ONE OF THESE ARGUMENTS STATES THE PHYSICIST'S VIEW. WHICH ONE? (CHECK CAREFULLY).</u>

EXPLAIN WHY? ____

INERTIA
SKATEBOARD EXPLANATION - ANSWER SHEET #2

QUESTION 1: WHAT IS THE MAIN REASON THE MORE MASSIVE SKATEBOARD WOULD BE HARDER TO STOP?

a.) More mass means more friction. Physicist's view: (True but if this were the main effect, the larger mass would have been easier, not harder to stop. This does happen with some skateboards with really bad bearings.)

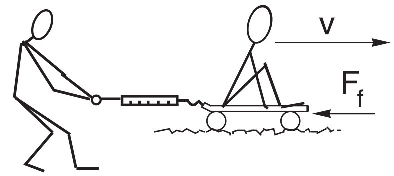


Figure 7.23

b.) Greater "hold down tendency" (gravitational force). Physicist's view: (More mass means more "hold down", but this is in the wrong direction to oppose motion. Also, if this were the dominant effect the larger mass would have been easier, not harder to stop).

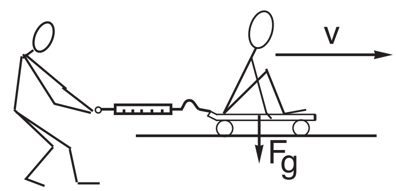


Figure 7.24

c.) **Physicist's explanation: the inertia property of mass.** Each masslet has *inertia* and resists being decelerated. Therefore, more masslets mean the object is more difficult to slow down. This is the physicist's explanation. We have been calling this aspect of *inertia* the "keep going property" of mass.

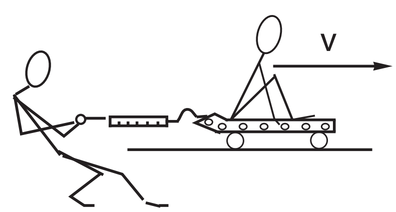


Figure 7.25

INERTIA - SKATEBOARD LAB - ACTIVITY #1

Name: ____________________

Period: _____Date: __________

INTRODUCTION

Have you ever wondered:

- What it takes to get something moving or keep it moving?
- What does the mass of the object have to do with it?
- If you keep exerting a force on something what will it do?

To find out you will need a stopwatch, meter stick, masking tape, force measurer (spring scale), twine, skateboard and a group of three students.

Please fill in your prediction before you actually do the experiment. The act of predicting is an important part of learning. Whether your prediction is right or wrong will not affect your grade, so please don't change your prediction if it turns out to be wrong.

PROCEDURE I: DESCRIBING MOTION CAUSED BY A CONSTANT FORCE

1.) With pieces of masking tape mark the floor every two meters for a maximum of 20 meters.

2.) Have a small person in your group sit on the skateboard or cart and loop a piece of heavy duty string around his/her waist. Be sure it is very loose.

3.) Hook the force measurer on the loop of string.

4.) Your partner on the skateboard or another person in your group should have the stopwatch.

5.) Pull and keep the force measurer reading as close to 15 N as possible. This may take some practice. As soon as you begin to pull the person on the skateboard you should start timing. Read the stopwatch every time the skateboard crosses a tape mark. A third person in your group should be writing down the times. In order to keep the force measurer on 15 N you must keep ahead of the skateboard. If you let the force vary too much you should repeat the trial. You may have to be quick.

a.) What was the time at each of the tape markers? (Make a data table).

b.) Looking at the data above, what kind of motion does the skateboard have when you provide a constant force of 15 N? (accelerated, decelerated, constant speed). Explain your choice.

____

____

PROCEDURE II: THE EFFECT OF MASS ON MOTION

1.) What do you think will happen if the mass of the person on the skateboard is larger?

Prediction:

____

____

2.) Get a big person in your group (or two small people) to sit on the skateboard and repeat the experiment. Be sure to take time measurements and record your results. (Create another data chart or add a section to the first chart.)

3.) What was different about the motion of the skateboard with a larger mass? Was the motion still accelerated? Explain.

____

____

PROCEDURE III: ROLE OF FRICTION

1.) Suppose your partner sat on the skateboard and you pulled him/her with a steady 15 N force for 10 meters. Then you eliminated the force, allowing him/her to *coast.* How far do you *predict* your partner will coast with no force from the force measurer? Give a rough estimate of the distance.

Prediction: ____________________

2.) Explain your prediction. What ideas did you consider?

3.) Compare your prediction with the actual results after doing it.

4.) What role does friction play in this result?

5.) Why doesn't the skateboard stop immediately at the point where the puller lets go?

6.) Suppose there were less friction, how would that affect the result?

7.) Suppose there were no friction, how would that affect the result?

IV. TO SUM UP

Write responses to the following questions:

1.) What kind of motion is caused by exerting a steady force on something?

2.) What effect does greater mass have on motion?

V. CHALLENGE QUESTIONS

1.) How would you expect the coasting distance of an old skateboard (with rough bearings) starting at 10 mph to change with two students on it instead of one student?

2.) How would you expect the coasting distance of a new skateboard (with low friction bearings) starting at 10 mph to change with two students on it instead of one student?

3.) How would you determine experimentally the amount of friction force acting on a skateboard moving along with a student riding on it?

QUIZ AND TEST QUESTIONS - INERTIA

1.) Jane acts as a brake by pulling back on a 140 kg sled moving on a frictionless ice pond to decelerate it from ten m/sec to zero m/sec. Later, she performs the same action on a 160 kg sled in the same amount of time. Did she exert more, less or the same amount of force in the second case? _________

Give a careful statement of the reason for your answer.

2.) By following and holding an air blower 20 cm behind a hockey puck, Joe applies a constant forward force to the puck for ten seconds. He then applies the force to the front of the puck to slow it down. Assuming the ice is frictionless, will it take more, less, or the same force to slow the puck to a stop in ten seconds? __________

Give a careful statement of the reason for your answer.

3.) Puck A hits stationary puck B of the same mass head on at 30 m/sec. It is observed that puck A stops dead in its tracks, while puck B shoots off at 30 m/sec. What does this say about the relative size of the forces exerted by A on B and by B on A?
____

Explain, using the concept of inertia and the terms "hold back" and "keep going".

4.) The drawing shows a coin resting on a card placed on top of a drinking glass. If one hits the card sharply, it will fly off horizontally while the coin falls into the glass. Using the concept of inertia, explain why the coin doesn't fly off with the card.

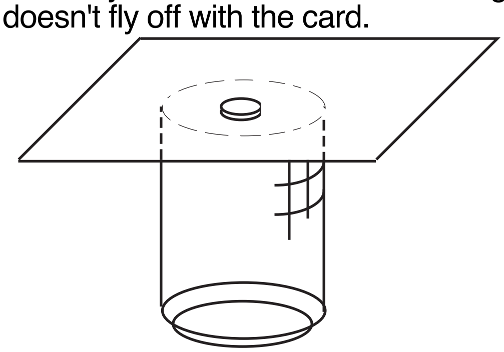


Figure 7.26

5.) Using the concept of inertia, explain why the ball on the symmetric track shown will rise approximately to the same height on the opposite side from its starting point.

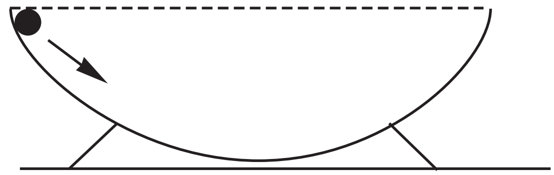


Figure 7.27

6.) The frictionless railroad cars are attached by cables. The engine applies a constant force of 500 N accelerating the cars. Is the tension in A greater than, less than, or equal to the tension in B? _______________ Explain.

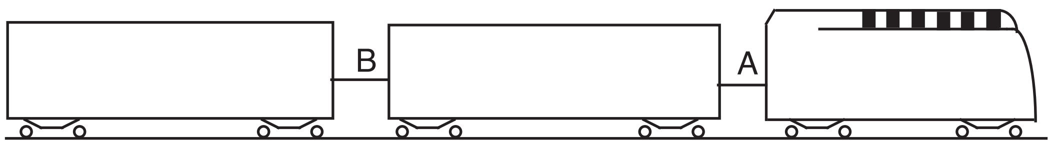


Figure 7.28

7.) If we could take a frictionless skateboard to another planet where the force of the planet's gravity pulls on each kilogram of mass twice as hard as the force of the Earth's gravity, how would the Skateboard Lab Activity #1 results be different? That is if you applied a steady force of 15 N for ten seconds on both planets, how would the results differ? Explain clearly.

8.) Note: A teacher could modify the Pre-Quiz for this unit (assume no friction) and then any or all of the Pre-Quiz questions would be very appropriate as quiz or test questions.

UNIT 8

Inertia and Gravitational Force

UNIT #8 - INERTIA AND GRAVITATIONAL FORCE

I. OVERVIEW OF THE INERTIA AND GRAVITATIONAL FORCE UNIT

A. MAJOR PRECONCEPTIONS POSING DIFFICULTIES IN THIS UNIT

1.) Mass and weight are not clearly differentiated.

2.) The tendency of an object to resist acceleration (inertia) is non-existent in space (since weight does not exist in deep space).

3.) A larger mass is not harder to accelerate than a smaller mass in space.

4.) Astronauts are nearly weightless in orbit because the force of gravity is nearly zero at that altitude.

5.) It is more difficult to start than to stop an object in space.

6.) Inertia is responsible for the extra force needed to just start an object moving.

7.) Gravitational force is totally or partially responsible for the inertial property of mass.

B. GENERAL STRATEGY OF THIS UNIT

This unit unit builds on previous lessons establishing ideas of the existence of inertia and gravitational force. This unit addresses two major objectives: the existence of inertia in space (and its dependence on mass) without gravitation; and the ability to give a coherent explanation of events in which the inertial and the gravitational property must be considered simultaneously. The major case we will consider is the problem of why objects with unequal mass fall at the same rate.

Even though this unit has been preceded by two units on gravity and one on inertia, teachers find that the preconceptions posing difficulties here are extremely difficult to remediate. Although students may have learned to think about the gravitational and inertial properties of mass separately, they frequently encounter trouble with questions which require holding both concepts in mind simultaneously.

The first day's lesson is focused on helping students form a clearer understanding of space, for many students have vague notions about this environment. The lesson starts with an activity that reviews the "keep going" and the "hold back" properties. Then the lesson presents the target problem about astronauts dealing with the "hold back" aspect of inertia in space. Next, an anchor situation is considered as astronauts deal with the "keep going" property of inertia in space. This is followed by NASA videotape(s) of astronauts living in an orbiting space shuttle, which are presented as evidence that the inertia property still is present in this environment. One suggested video contains a video clip of water hitting and deflecting a towel aboard a space shuttle.

The second day's lesson begins with a classic discrepant event. Two objects of very different mass are dropped from the highest available place. The ensuing discussion challenges students to question their understanding of *why* objects of different mass have equal falling rates. The paradox of different masses falling at the same rate is related to the question of whether the Earth must pull harder on the more massive object to accelerate it. Students are then asked to connect Newton's second law to their new understanding through another demonstration with carts on a table.

The lesson wraps up with a review of the free fall situation using the “masslet” model and one more free fall bridging example. A number of homework problems are offered so teachers may choose the level at which they wish to challenge their students.

C. THE PHYSICIST'S VIEW

The issue of inertia in outer space is one that demands careful attention from physics teachers. With students who are just beginning to differentiate the inertial and gravitational properties of mass, we must help them look very carefully for *evidence of inertia* as still present in a zero gravity environment. While it is fun to watch things float around in space videos, we need to encourage students to pay careful attention for evidence of the inertia property that is still present in orbit or in interstellar space.

The notion of a gravity-free (weightless) environment that one would find in interstellar space is impossible to duplicate on Earth or in Earth orbit. When we show space shuttle movies, we are observing an environment that "appears" to have no gravity, but is actually a “free fall” situation. Teachers should be aware of the fact that the force of gravity acting on an orbiting astronaut is still a very significant fraction of that person's weight on the Earth's surface. In other words, the orbiting space shuttle is falling down as it goes around the Earth in a circular orbit. Thus, it feels the same inside the orbiting craft as it would in interstellar space. This matter is covered nicely in the NASA film "Zero-G" which makes the distinction between the idea of a true "weightless" environment and the "apparently weightless" environment of an orbiting space craft. Teachers of more advanced classes should seriously consider including a solid understanding of this issue as one of their course objectives.

As we wrap up this work on mass, it is worth one more careful look at the inertial and gravitational properties of mass which help us understand the "free fall" problem of equal accelerations. Some teachers prefer to use the terminology “inertial mass” and “gravitational mass” to represent these two properties of mass, but we should remember that these are two aspects of mass that have been shown experimentally to be proportional to a very high level of accuracy.

A careful examination of our earlier studies in free fall will lead us to the notion of one acceleration for all masses. As problem solvers we are often casual about expressing Newton's second law or:

$$F_{net} = ma \quad \text{or} \quad a = F_{net} / m$$

However, when we are concerned about the magnitude of the free fall acceleration due to a gravitational force, we should be careful to use the inertial property of mass.

$$a = \frac{F_g}{m_i}$$

Thus, F_g represents the force of gravity, and m_i represents the inertial mass, as we are using the "law of inertia."

Now consider the force of gravity which is caused by the Earth's gravitational field is properly found below.

$$F_g = m_g g$$

where m_g represents the gravitational mass of the object and g is the gravitational field strength which equals 9.8 newtons/kg. That is, the Earth exerts a force of 9.8 newtons on each kilogram of gravitational mass near its surface.

Combining our work with gravity and inertia, our acceleration expression becomes

$$a = \frac{m_g\, g}{m_i}$$

in which we know $m_g = m_i$. Thus, we are led to the value of $a = 9.8\ m/s^2$ for the acceleration of gravity through the equality of the inertial and gravitational properties of matter.

II. INERTIA AND GRAVITATIONAL FORCE – LESSON 1

A. OVERVIEW OF THE LESSON

The main objective of this lesson is to solidify the student's understanding that inertia still exists in an environment where there is no gravity, or in which there appears to be no gravity. Since many students have an intuitive sense that very large objects have a "keep going tendency" even in "zero-g" situations where there is an apparent absence of gravitational force, we build from that concept as an anchor. We use it to establish the presence of a "hold back tendency" in the "zero-g" environment. Finally, some NASA video examples showing inertia in a "zero-g" environment are used along with more examples and discussion to achieve the major goal of the lesson.

B. MATERIALS

1.) Pre-Quiz and Lab Activity Sheets

2.) Lab Activity materials for each lab station (or one demonstration)
Two dynamics carts
One brick
Two 100 gram masses and string
One meter stick

3.) Video (see Teacher's Notes about source)
"Eating and Sleeping in Space" (NASA)
"Zero-G" (NASA)

4.) Voting sheets

5.) A 10 kg or 25 lb mass that can be suspended such as a lead brick or a barbell mass.

6.) One regular basketball and one basketball loaded with sand

7.) Two skateboards or carts

8.) Homework - Inertia and Gravitational Force - Day #1

C. OBJECTIVES

1.) The student should understand that mass and inertia exist in space.

2.) The student should understand that the "keep going tendency" equals the "hold back tendency" even in an environment without gravity.

3.) The student should understand that the astronauts in orbit are not weightless but only appear to be weightless (more difficult level).

D. CONCEPT DIAGRAM – INERTIA AND GRAVITATIONAL FORCE - DAY #1

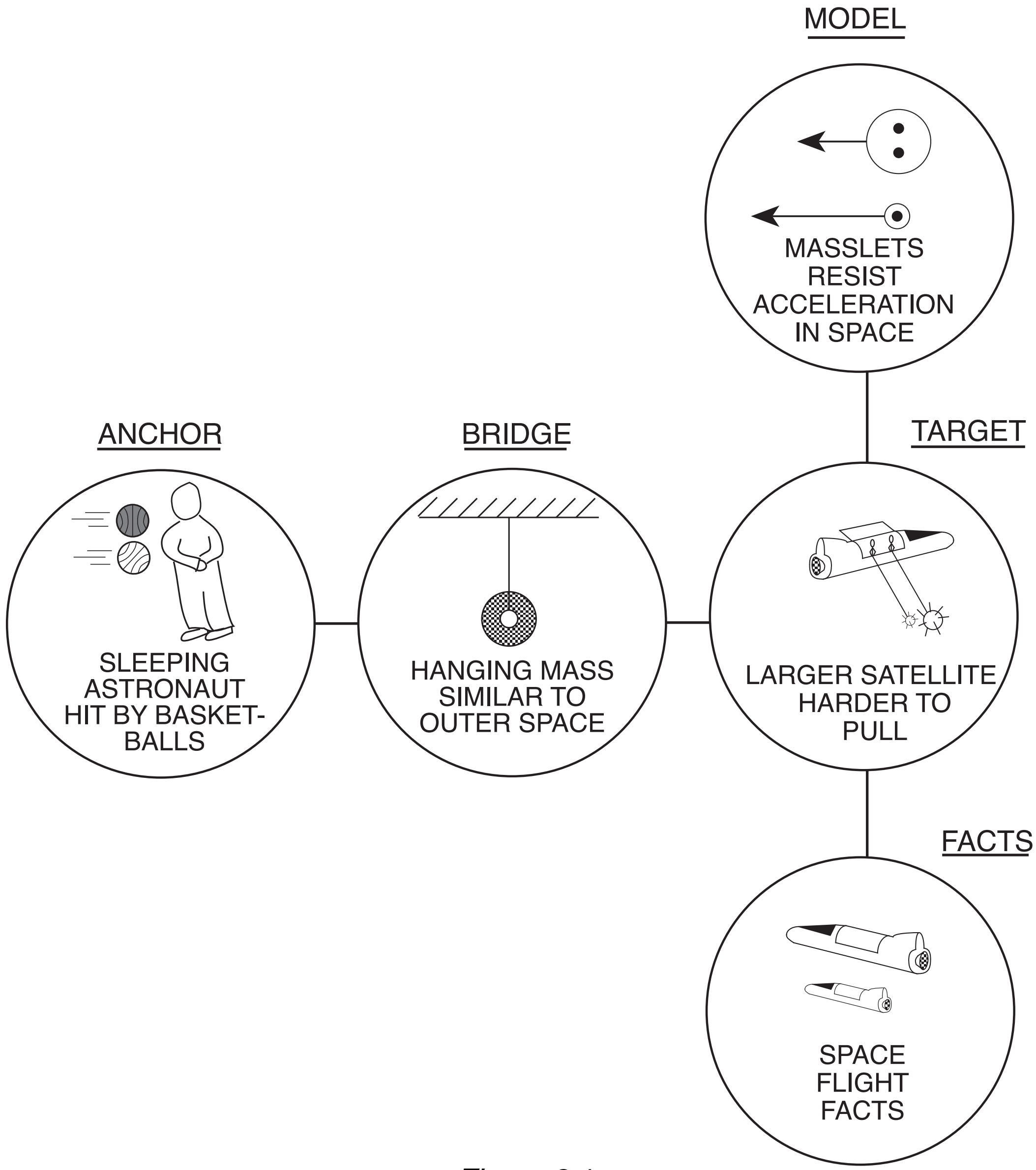


Figure 8.1

E. LESSON PLAN - INERTIA AND GRAVITATIONAL FORCE - DAY #1

1.) Pre- Quiz and Lab Activity

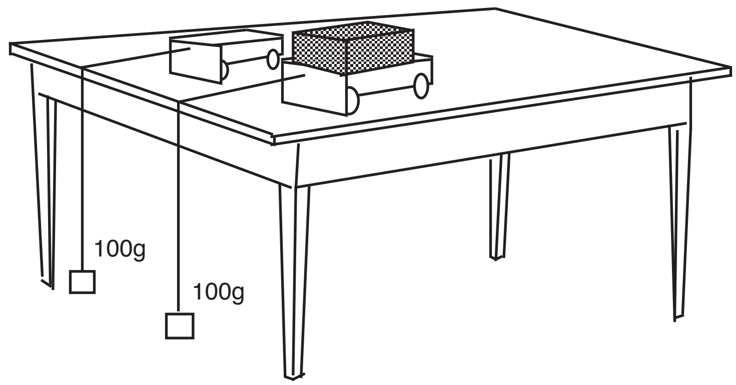


Figure 8.2

a.) Have the students individually write out the two predictions called for on the Pre-Quiz and Lab Activity Sheet.

b.) Then the teacher should gather the class around one lab table to show how to hold the meter stick and simultaneously shove the two carts at the same speed. Use equal mass carts for the demonstration so they will not know what will happen when they try the experiment as requested. Ask the groups to work on this at their own lab tables, and watch out for groups that assume the carts "feel equal force" rather the carts experience "equal change in velocity."

c.) This activity is short (10-15 min.). Teachers who can not provide equipment for each lab group may need to do this as a class demonstration. The activity is highly recommended in either case.

2.) Introduce the vote on the target problem

a.) *Draw Figure 8.3*

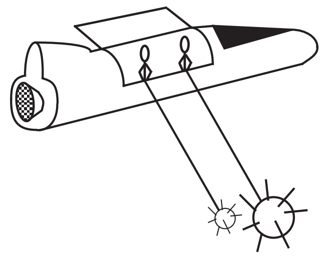


Figure 8.3

b.) *Explain the setting*

Two astronauts are in deep space, far from Earth and other planets, trying to pull satellites into the cargo bay of their space ship. One satellite has a mass of 25 kg and the other has a mass of 15 kg. Both astronauts pull steadily for five seconds and then allow the satellite to coast toward them. If they do it correctly, the satellites will arrive at the same time.

c.) *Ask the question - Vote #1*

Will the force on the larger mass for 5 seconds need to be greater, less than or equal to the force on the smaller mass for 5 seconds?

- The force on the larger mass needs to be greater.
- The force on the larger mass needs to be smaller.
- The force on the larger mass needs to be the same.

3.) Discussion of Vote #1

Draw out different points of view without resolving the issue.

As soon as the idea of inertia comes up in the discussions, *review* the terms "hold back tendency" and "keep going tendency", and the idea that they are both examples of the inertia property of mass. This would be a *good time to raise the question*: "Does inertia exist in outer space where there is only a tiny gravitational force?"

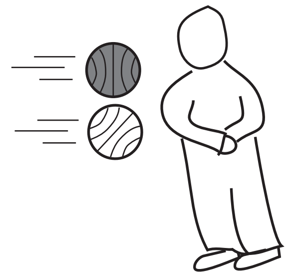


Figure 8.4

4.) Introduce the Anchor Problem

a.) *Present the situation and draw Figure 8.4*

The Situation:
You are asleep in a zero-g space station far away from any planets.

b.) *Vote #2 Question*

Which has a better chance of waking you up?

- A basketball filled with *sand* traveling through space and colliding with you at five mph.
- A normal basketball filled with *air* traveling through space colliding with you at five mph.
- Each has an *equal* chance of waking you up.

c.) Discuss this vote as needed

5.) Present video evidence of inertia in space[1]

Show about ten minutes of video evidence of inertia in space. Consider the following:

- "Eating and Sleeping in Space" (NASA) scene where engines fire and sleeping astronauts hit their heads

---

[1] Since we cannot feel what the astronauts feel, the indirect evidence for inertia in these films is hard for some students to identify with intuitively.

Refer to Teaching Notes for video sources.

6.) <u>Present more facts</u>

- *Larger meteorites* make deeper dents in a space ship than smaller ones, other factors being equal.

- Two masslets are twice as hard to decelerate or accelerate as one masslet. (Draw the model into the concept diagram)

7.) <u>Hanging 10 kg mass simulates outer space inertia</u>

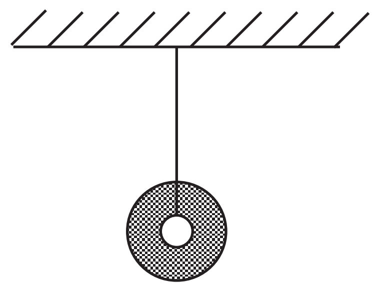


Figure 8.5

Demonstrate the behavior of a suspended 10 kg mass hanging on a rope. One can easily move it slowly with one finger. However, punch it or shake it vigorously and the resistance to acceleration becomes very noticable.

Some students could try it and report back to the class.

Other students can try shaking it sideways vigorously.

During the discussion emphasize the fact that the students did not need to support the weight as it was effectively floating. Therefore, they were only experiencing the inertial property and not the gravitational property.

8.) Basketball/skateboard demonstration[2] (if time is available)

a.) Have two students, of equal mass, sitting on skateboards (or other low friction carts) demonstrate vigorously throwing a basketball between skateboard riders.

b.) Tell the class that this situation is equivalent to outer space if the skateboard bearings are low in friction.

c.) Ask the class to point out examples of both "hold back" and "keep going tendency" in this simulated outer space environment. On a level floor the velocities should be nearly equal and opposite providing strong evidence that "hold back" equals "keep going".

Figure 8.6

9.) Review concept diagram

Review the concept diagram examples on the chalkboard. Conclude that:

The two aspects of inertia, the "hold back" and "keep going" tendencies of mass are not caused by gravity and are the same in space as they are on Earth.

10.) Discussion question

"Using examples from our discussion in class, explain how the astronauts pulling satellites of different mass is like the astronauts trying to stop the oncoming space vehicles." This can be a group discussion or individual in-class writing assignment.

11.) Assign homework

Homework – Inertia and Gravitational Force - Day #1

[2] You will need something like a volleyball or a basketball full of sand (25-30 lbs.). The students must practice throwing and catching the heavy object before they get on the skateboards. We definitely recommend the sitting position for safety.

F. TEACHING NOTES - INERTIA AND GRAVITATIONAL FORCE - DAY #1

1.) Some careful selection and planning of appropriate segments of NASA video material is important. One needs to look carefully for evidence of inertia in the "Zero-G" environment because many students have the gravity and weight concepts confused with the inertial properties of mass. Our recommendation is the scene when the rocket engines on the shuttle are fired and sleeping astronauts hit their heads. We feel the "Zero-G" video is very appropriate for teachers who wish to go beyond the scope of this lesson and clarify the difference between the notions of zero weight and zero apparent weight of objects in orbit.

To obtain these videos from the NASA website:
http://corecatalog.nasa.gov/, referenced 15 October 2009
select: How to Order
a.) Title: Eating and Sleeping in Space
Item number 006.3-04V
b.) Title: Skylab 6-part series
Item number 009.0-08V
Note: Program 1 is "Zero-G"
c.) "Candid Shots in Space" is no longer available from NASA

2.) The demonstration with a suspended 10 kg mass may not convince all students that inertia does exist in outer space, but it does get their attention. While some teachers have found a lead brick to be very effective, they are now hard to find. A 25 lb mass from one end of a barbell set should work well or a 25 lb block of iron if you can find one. Notice you may use this item for the free fall demonstration in Day #2.

3.) The demonstration with the loaded basketball and the students on the skateboard will probably work well if the skateboard has good bearings. Check the demonstration out ahead of time. Select an area with a level floor and have the students practice throwing and catching before they try this on the skateboards. They should definitely do this in a sitting position for safety and to provide stability.

A careful analysis of this interaction should lead the teacher to notice that the change in velocity of the ball is a little greater for the thrower than the catcher. Because the mass of the basketball is small relative to the masses of the students, the two final skateboard velocities should be nearly equal and opposite.

III. INERTIA AND GRAVITATIONAL FORCE – LESSON 2

A. OVERVIEW OF THE LESSON

This lesson starts with a demonstration of equal falling rates for unequal masses. The situation is carefully developed as a paradox to encourage students to deepen their conceptions. If the students each hold the 2 masses just before they are dropped, they will find it hard to believe the rates should be equal.

Another demonstration is carried out with students pulling on carts of unequal mass in order to produce equal accelerations. Since the larger mass requires a larger force, the issue of inertia is raised and then compared to the problem of unequal masses dropped from far above the Earth.

Students are eventually asked to imagine how hard they would have to pull on objects "if they were the Earth" and then the compensation argument is presented. Students are encouraged to think simultaneously about a larger mass that feels a larger force of gravity while the same larger mass has more inertia (resistance to acceleration).

B. MATERIALS

1.) One 10 kg mass and one 1 kg mass for the equal falling rates experiment.
A 25 lb barbell weight and a clay brick should work. A second floor window with ground outside is a very desirable site. Very thick padding would be needed on any inside floor to prevent damage from even an 8 or 10 ft. fall in a classroom or down a stairwell.

2.) Voting sheets

3.) Vacuum pump and tube with penny and feather (optional)

4.) Two dynamic carts four bricks, and two spring scales for the demonstration. One set up for each group if an activity is desired.

5.) Homework sheets - Inertia and Gravitational Force - Day #2

C. OBJECTIVES

1.) Students should understand that equal falling rates with unequal forces seems paradoxical to many people.

2.) Students should be able to explain the analogy between the Earth pulling objects with gravity and astronauts pulling objects into a space ship.

3.) Students should be able to state a compensation argument to explain why objects fall with equal acceleration.

D. CONCEPT DIAGRAM - INERTIA AND GRAVITATIONAL FORCE - DAY #2

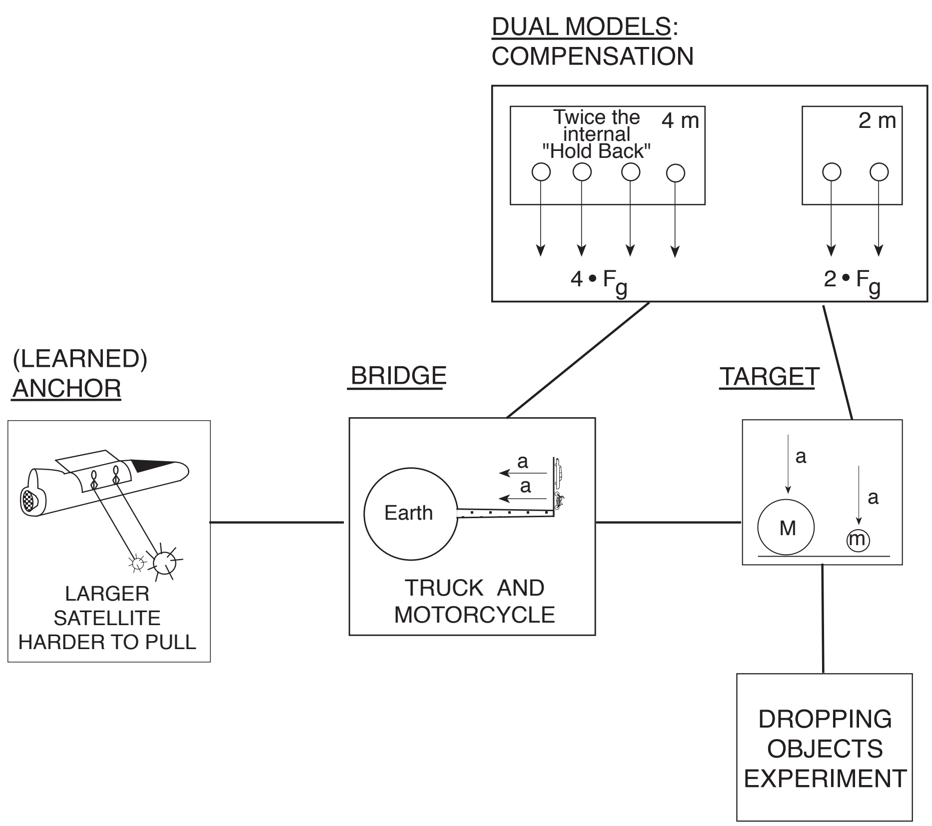


Figure 8.7

E. LESSON PLAN - INERTIA AND GRAVITATIONAL FORCE - DAY #2

1.) Discuss homework questions from Day #1

2.) Free Fall Demonstration

a.) Select two items of very different mass, such as a barbell weight or a lead brick (11 kg) and a regular clay brick (1-2 kg).

b.) The teacher should take these two items to each student and place one in each hand as the student is sitting at his or her desk. Then ask "Which do you think will get to the ground first if we drop them?"

c.) Take Vote #1 with voting sheets.

Choose which item will get to the ground first, Figure 8.8. Emphasize your request for a makes sense score.

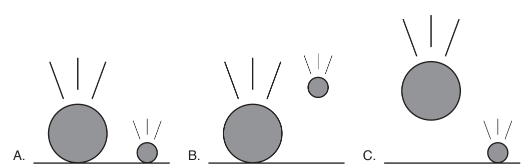


Figure 8.8

d.) Then take the class outside and drop the two masses from a second story window or arrange the best drop you can find somewhere else. This should cause some internal conflict for a number of students.

3.) Free Fall Discussion

a.) Ask volunteers to explain how they make sense of this situation. Perhaps request helpful analogies. The teacher should try to hold back an explanation at this point.

4.) Demonstrate dropping a coin and a sheet of paper

a.) Ask why paper does not fall as fast as the coin. Agree that air friction dominates here. Compare the falling rate of a crumpled sheet of paper with a whole sheet of paper.

b.) *State* that air friction plays a negligible role with the dense objects in the original experiment.

5.) (Optional demonstration) Drop coin and feather in an evacuated tube

Compare the falling rates of a penny and a feather.[3]

6.) Examine the forces acting on unequal masses

a.) *Ask the question for Vote #2*

Consider the first free fall experiment with big masses. Did both objects have the same force acting on them or did one have a greater force acting on it? (Ignore friction). Comment on the importance of the makes sense score here.

b.) *Choices for Vote #2*

- Same force acts on both.
- Different forces.

c.) *Discuss the vote*

A number of students may say "same force." Aim for *controversy* rather than closure here if possible. (Ask students who voted "same force" to explain their answers).

7.) Demonstration with dynamic carts[4]

(to show unequal forces for unequal masses accelerating equally.)

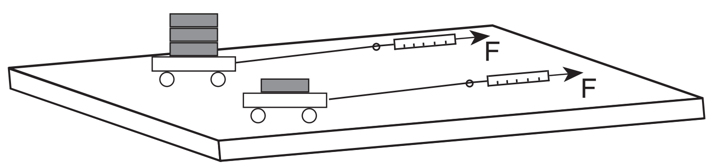


Figure 8.9

a.) Assemble the set up in Figure 8.9 and have two students help. Tell them to pull the 2 carts with the same acceleration. Have them practice starting together and reaching the end of the table together. Additional students should observe the readings on the force meters. Hopefully, the ratio of the forces will be *roughly* equal to the ratio of the masses.

[3] One would certainly skip this if it has been done earlier in the course.

[4] Some teachers may wish to skip this demonstration if they have dealt with this situation in earlier laboratory work.

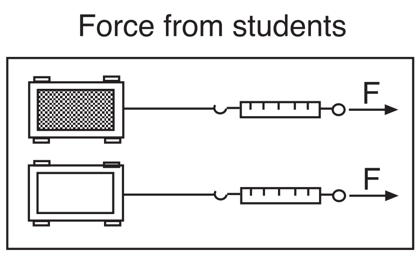
b.) Ask follow up questions:

- What do you notice about the force pattern?
- Why does one cart require more force?

c.) Clarify the teacher's position that the massive cart requires more force because it has more inertia.

8.) <u>Transfer from dynamics carts to free fall</u>

a.) Ask for students to connect the dynamic carts demonstration to the free fall problem. Why do the falling objects reach the floor together?



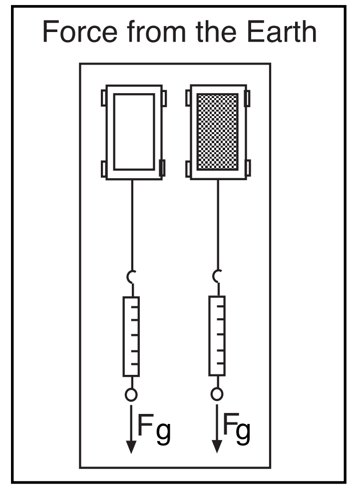


Figure 8.10 *Figure 8.11*

b.) Construct a masslet diagram for two falling objects showing gravitational force vectors.

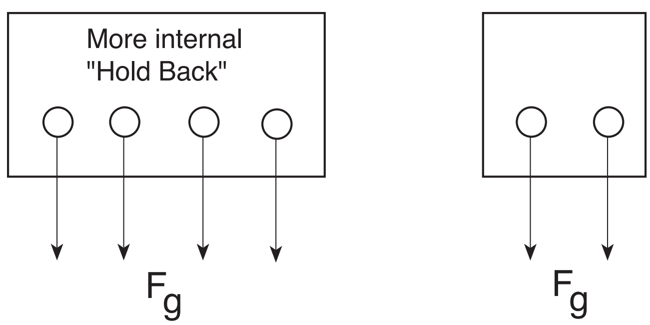


Figure 8.12

c.) Here we have the paradox that the lighter object falls just as fast, but the forces are unequal. *Announce that you would like everyone to resolve this paradox by the end of the lesson so it makes sense to them.*

9.) Introduce a bridging example (Vote #3)

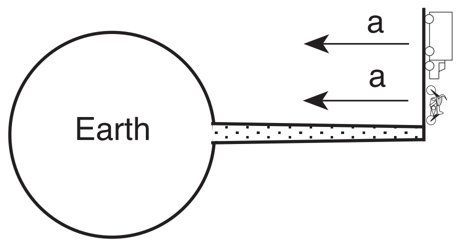


Figure 8.13

a.) Draw the diagram (Figure 8.11) on the board.

b.) Set up the scene as follows:

"In a rigorous impact test, engineers drop a motorcycle and a truck, with 10 times as much mass, from a giant 20 mile high tower so that they fall toward the Earth. Ignore air resistance."

c.) *Discuss and confirm the role of gravity*

If we could turn off the gravitational force of the Earth the objects would not fall.

d.) *Ask the question - Vote #3*

"If you were the Earth which would be harder for you to accelerate towards you at the same rate, the Truck or the Motorcycle?"[5]

e.) Choices:

- I would have to pull harder on the Motorcycle.
- I would have to pull harder on the Truck.
- I would have to pull equally hard on both the truck and the motorcycle.

Write a brief explanation of your vote in the space on the voting sheet.

[5] This question is carefully worded to help students focus on both critical issues.

10.) <u>Review the anchor problem</u>

a.) At an appropriate point in the discussion, review the astronauts pulling satellites analogy and draw it on the left side of your concept diagram on the board (see Figure 8.7).

b.) *Compare the analogies (in the concept diagram)*

Compare the problem of the astronauts needing to exert a larger force on the larger satellite to the problem with the truck and motorcycle.

c.) As a wrap up, ask the students to remember how much more the big mass felt attracted to the Earth.

Then point out the fact that it is the EARTH that exerts the force that pulls on the masses. Thus, the Earth is the "agent" that must pull harder to overcome the greater hold back property of the big mass.

11.) <u>Summarize with the compensation argument</u>

a.) Review Figure 8.10.

b.) Ask the class to suggest additional creative ways to symbolize the compensation argument.

c.) Offer the presentation below if you feel it will help your class.

$>$ m causes $>$ Force causes $>$ a

$>$ m means $>$ Inertia thus $<$ a

$$a = \frac{F}{M} = 10 \text{ m/s}^2 \qquad a = \frac{f}{m} = 10 \text{ m/s}^2$$

12.) <u>Review the concept diagram from Day #2</u>

13.) <u>Homework</u>

Assign Homework - Inertia and Gravitational force - Day #2.

F. TEACHING NOTES - INERTIA AND GRAVITATIONAL FORCE - DAY #2

In this lesson we are trying to simultaneously apply the inertial and gravitational properties of mass in the context of free fall problems. Remember it is hard for students to hold both of these ideas in mind simultaneously so a good deal of practice is needed.

There may be more examples in this lesson than your class needs, but many students may benefit from the practice. We feel the compensation arguments at the end of the lesson are vital to help students remind themselves that they must keep two concepts in mind simultaneously in order to explain the equal acceleration of free fall.

As in earlier lessons, the concept diagram is important to help students focus on the main arguments in the lesson and to help them compare analogies. The diagrams are included in the lesson to be drawn on the board when appropriate.

There are a number of homework problems designed to give students practice thinking about both gravitational force and inertia simultaneously. In addition, there are more homework problems at the end which offer students an opportunity to descriminate between the importance of friction force, gravitational force, and inertia in a variety of physical problems. Some of these problems could be useful on tests or final exams. Careful discussion of the problems the following day in small groups may help to solidify these concepts.

Teachers of advanced classes could consider the following:

a.) View the NASA video "Zero-G".

b.) Discuss the difference between being truly "weightless" and "apparent weightlessness" which results from the free fall condition of orbital motion.

V. MATERIALS FOR DUPLICATION

A. PRE-QUIZ ACTIVITY

B. HOMEWORK PROBLEMS

1.) Homework – Inertia and Gravitational Force - Day #1

2.) Homework – Inertia and Gravitational Force - Day #2

C. QUIZ AND TEST QUESTIONS - INERTIA AND GRAVITATIONAL FORCE

INERTIA AND GRAVITATIONAL FORCE - PRE-QUIZ ACTIVITY

Name: ____________________

Period: _____Date: __________

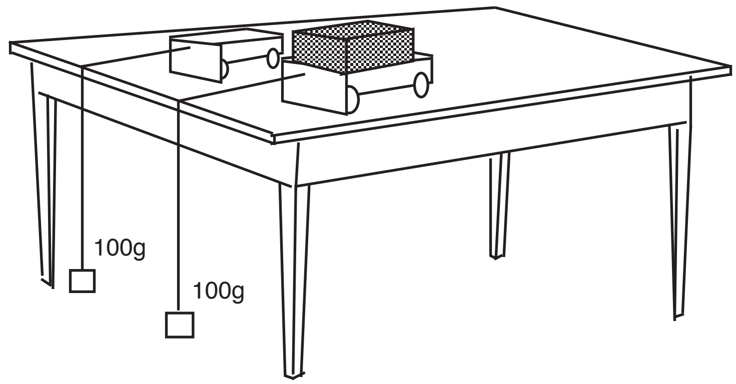


Figure 8.14

Before this laboratory you are asked to *Predict* what will happen in two situations.

If both carts above are given the **same initial velocity** to the right, which one will slow down more quickly and stop first, the more massive or the less massive cart?

Do not try the experiment until you have written your prediction below.

Prediction: ____

____

1.) *Set up* the apparatus as shown in the drawing. In order to get the carts moving at the same initial speed, you will be pushing both carts at once with a single ruler held behind them. Two equal weights hanging over the table edge will be used to supply a backwards force on the carts opposing their motion.

2.) *Analyze:* What factors will be the same for both carts?
- a.) Speed leaving the push of the ruler
- b.) Tension in the strings
- c.) Mass of the carts
- d.) Distance the carts travel
- e.) Deceleration of each cart

3.) *Analyze:* What factors will be different?
- a.) Speed leaving the push of the ruler
- b.) Tension in the strings
- c.) Mass of the carts
- d.) Distance the carts travel
- e.) Deceleration of each cart

4.) *Test* your prediction by trying the experiment a few times. Record your results.

5.) *Predict* whether the original hanging masses will *speed up* the carts from rest at the same rate. You should release the carts simultaneously from the far end of the table.

a.) Prediction: ____

____

____

b.) Change the set up and test your prediction. Record your results.

6.) *Carefully explain* your results in parts 4 and 5 using some of the following terms: velocity, "hold back property" of mass, "keep going property" of mass, inertia, mass, friction, "hold down tendency", acceleration, deceleration.

HOMEWORK - INERTIA AND GRAVITATIONAL FORCE - DAY #1

Name: ____________________

Period: _____Date: __________

1.) A watermelon is taken up into deep space in the space shuttle. Discuss how the following properties are affected.

a.) density

b.) volume

c.) mass

d.) weight

e.) number of masslets

f.) color

g.) inertia

h.) heart rate

2.) If the "keep going tendency" of inertia is equal to the "hold back tendency" of inertia, do you think it takes as much fuel to start a rocket in deep space as it does to stop it? Explain your answer.

3.) In your own words, what is inertia?

4.) What is the difference between the gravitational force and inertia?

5.) The Starship Enterprise has broken down in deep space and needs a space tug. With only a thirtieth of the mass of the Enterprise, a very small space tug rockets up and attempts to move the Enterprise forward with a steady 1.00 N force.

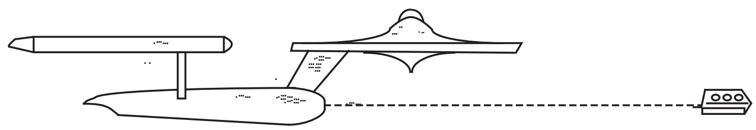


Figure 8.15

Choose one result and explain your choice:

a.) The tow vehicle easily pulls the Enterprise, because in space there is no weight.

b.) The tow vehicle can only accelerate the Enterprise slowly because it is so massive.

c.) The tow vehicle is too small to start the Enterprise moving.

d.) Other.

Answer: ____

Explanation: ____

____

____

6.) Is it possible to have inertia in a part of the universe that has negligible gravitational forces?

7.) Is friction one type of inertia? Explain.

8.) Does inertia cause friction? Explain.

9.) Two basketballs are ejected by launching devices from a space station (in deep space) and travel toward a space shuttle parked nearby. One ball is full of water (mass 20 kg) and the other ball contains air (mass 4 kg). The launchers are adjusted to shove the two balls so they will leave with equal speeds and reach the space shuttle in equal times.

a.) Considering the force exerted on each ball by its launching device, the force on the 20 kg ball is:

1.) The same as the force exerted on the 4 kg ball.
2.) Less than the force exerted on the 4 kg ball.
3.) More than the force exerted on the 4 kg ball.
4.) Other (fill in).

____

b.) The space shuttle door does not open and the two basketballs travel through space and strike the closed door.

Which ball will dent the door more?

1.) The 4 kg ball
2.) The 20 kg ball
3.) There will be no difference since there is no weight in deep space.

Give a brief explanation of your choice.

10.) Given two baseball-sized meteorites of exactly the same size but made of different material, how can one find out which has the greater density?

a.) Give two ways to find out on Earth.

b.) Give two ways to find out in space.

HOMEWORK - INERTIA AND GRAVITATIONAL FORCE - DAY #2

Name: ____________________

Period: _____Date: __________

1.) The coyote is looking for the road runner on his vacation to the Moon. He comes to a cliff overhanging a 100 meter drop. Suddenly, the overhanging rock cracks and breaks off with the coyote on it.

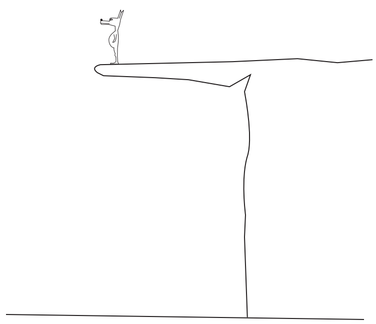


Figure 8.16

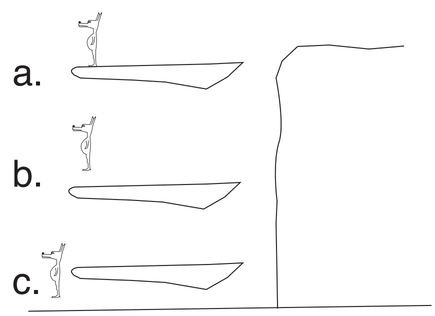


Figure 8.17

a.) Which has more force acting on it while on the way down, the rock or the coyote?

____

b.) Choose one of the situations you feel is correct as they fall to the Moon's surface.

Does the coyote stay on the rock, fall slower than the rock, or fall ahead of the rock?

Explain your choice using the masslet model as part of your explanation.

c.) If you said that the large rock "feels" more force than the coyote, does it reach the Moon's surface first before the coyote? ________________

d.) What would happen if the situation took place on the Earth? Explain how the results would compare.

2.) Suppose you weighed yourself on your bathroom scale this morning and found you weighed 120 pounds (440 N). Explain qualitatively what would happen to your *weight* and your *mass* at the following places:

a.) The Moon

b.) Jupiter

c.) Space (far from any planets and stars)

3.) Explain what inertia has to do with the idea that a very large object falls with the same acceleration (9.8 m/s/s) as a very small object.

4.) One large and one small cannon fire a large and small cannon ball at 300 mph straight up simultaneously. Ignoring friction, which will go higher if they each leave the barrel going 300 mph?

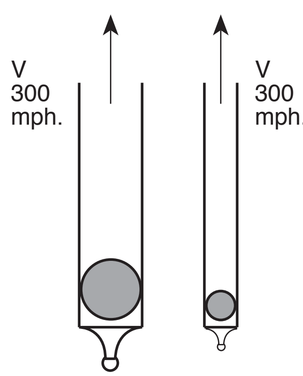


Figure 8.18

5.) Increasing the mass on the end of a clock's pendulum does not change the speed of the clock. Explain why.

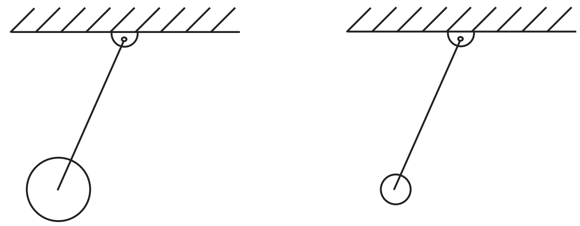


Figure 8.19

6.) a.) A low-mass object and a high-mass object are dropped from identical heights on identical planets as shown below. Which will hit first?

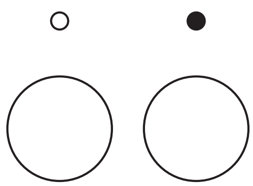


Figure 8.20

b.) Two identical objects are dropped on a low mass planet and a high-mass planet of the same size as shown below. Which will hit first? Explain your answer.

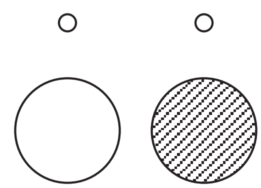


Figure 8.21

c.) Newton thought that when an object fell to Earth the Earth would also rise to meet the object. Usually we consider this upward motion of a planet negligible when we do problems about objects falling on that planet. How would your answer to part a.) change if you consider the tiny upward motion of the planets?

7.) Since there is no air (atmosphere) on the Moon, it should make it simpler to do experiments with free fall. What would happen if you simultaneously dropped a 100 kg boulder and a sheet of paper off a cliff on the Moon? Explain the result and compare the results to the same experiment on the Earth.

SUPPLEMENTAL HOMEWORK - GRAVITATIONAL FORCE, FRICTION FORCE, INERTIA

Name: ____________________

Period: _____Date: ___________

1. A student is trying to push a large wooden block across a rough concrete floor. She starts pushing gently, then pushes with increasing force until the block starts to slide. After the block begins to move, she continues to push the block across the room *at a slow and steady speed*. Later, she commented that she exerted the greatest force just before the block started to slide. Which of the three concepts, gravitational force, friction force, or inertia, is most useful in explaining the forces she experienced? Explain your choice.

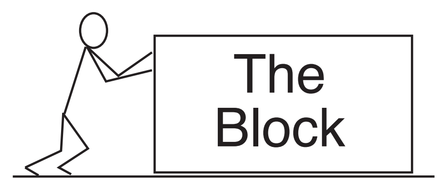


Figure 8.22

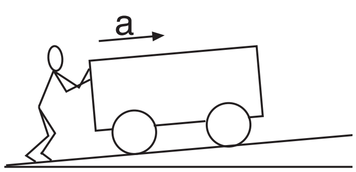


Figure 8.23

2. A cart, with wheels that spin easily, is being pushed up a gentle slope at a steady acceleration. Is the resistance the person feels primarily due to a gravitational force, a friction force, or inertia? Explain your choice.

3. A large block is being pulled to the top of a cliff at a slow and steady speed. Is the tension (force) in the rope primarily caused by the gravitational force acting on the block, the friction force acting on the block, or the inertia of the block? Defend your answer.

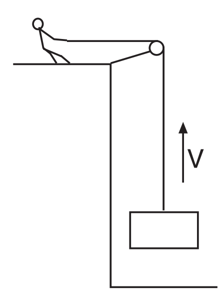


Figure 8.24

4. A cart with nearly frictionless wheels is coasting along on a smooth road. There is a rope attached to the back of the cart with a loop on the other end of the rope. An enthusiastic student runs up behind the cart, picks up the rope, and runs along holding the slack (with no tension) rope. Just as the cart is passing a fire hydrant the student throws the loop of the rope over a fire hydrant. The cart continues along and the rope becomes very tight, and then suddenly snaps apart. Would you say the rope broke primarily due to the force of gravity acting on the cart, the force of friction acting on the cart, or the inertia of the cart? Defend your answer.

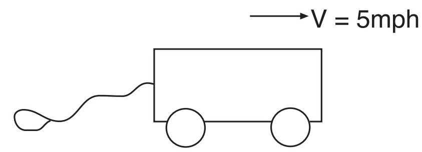


Figure 8.25

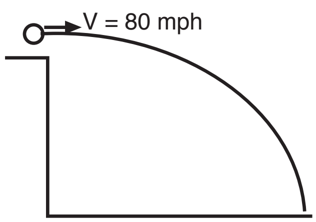


Figure 8.26

5. A metal ball is thrown sideways off the top of a cliff at a speed of 80 mph. The ball follows a curved path as it travels through the air. Identify and describe the primary factor(s) that could be used to explain the curved shape of the ball's path.

6. A person is using a rope to pull a rough cement block up a ramp that has a 5° slope. The block moves at a steady speed of one mile/hour. What is the primary cause of the resistance the person is feeling? Explain your answer.

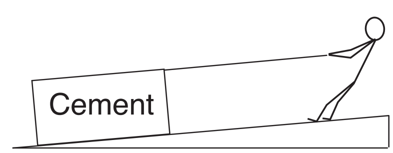


Figure 8.27

7. Fred's car ran out of gas and he had to push it to a gas station along a flat level road. As he started pushing on the car, he noticed that he had to push quite hard for a little while just to get the car moving. After the car began to move, he was able to push rather gently to keep it going at a speed of 2 MPH all the way to the gas station. What is the primary explanation for the difference between the force needed to just start the car moving and the force required to continue at *a steady speed*?

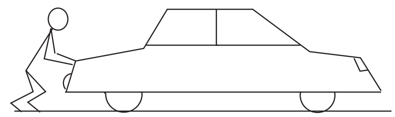


Figure 8.28

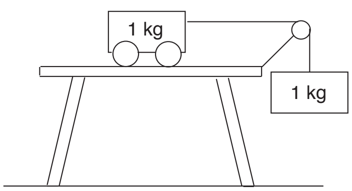


Figure 8.29

8. A hanging kilogram is attached to a low friction cart with the rope that goes over a frictionless pulley. As the mass is allowed to fall, it pulls on the cart causing it to accelerate. If you were to increase the hanging mass to 2 kg, what property(ies) of the extra kilogram, friction force, gravitational force, or inertia, should be considered in determining the new acceleration of the system? Explain your answer.

9. An enthusiastic physics student is pulling a low friction cart up a steep incline at a steady speed. The rope passes over a frictionless pulley and down to the student as shown. Which of the following concepts, friction force, gravitational force, or inertia, could be considered the primary cause of the resistance felt by the student as he pulls the rope? Explain your answer.

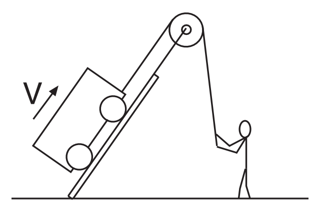


Figure 8.30

10. Which situation requires a greater force: accelerating a frictionless cart from rest to one mph in one second, or accelerating that same cart from one mph to two mph in one second? Explain your answer.

QUIZ AND TEST QUESTIONS - INERTIA AND GRAVITATIONAL FORCE

1.) Two catapults are used to launch a 100 kg man and a 50 kg boy astronaut out the door of a space station into space. Each catapult applies the same force to each person for exactly one second, and both are released simultaneously. Will the man and the boy astronaut leave the space station at equal speeds?

____

Sketch the velocity vs. time graph for each, and explain carefully.

2.) A quarter and a dime are dropped from the same height on Earth. Write a *carefully reasoned explanation* for why they will hit the ground at the same time (ignore friction).

3.) Suppose someone said to you "A heavy bowling ball will fall faster than a light baseball because the Earth exerts more force on it." As a confident physics student, how would you respond?

4.) A lead ball has a mass of ten kg and is thrown straight up in the air. Make a clearly labeled free body diagram, showing all of the force vectors acting on the ball, (including friction forces) for each of the following situations.
Label each force vector clearly.

a.) While it is going up

O

b.) While it is at the top turning around

O

c.) While it is falling down

O

5.) A 10 kg bowling ball and a 5 kg bowling ball are bowled horizontally off the top of a cliff (path) at the same speed. Is the heavier ball's trajectory different from the lighter ball's trajectory? Sketch the two paths and explain any similarity or difference.

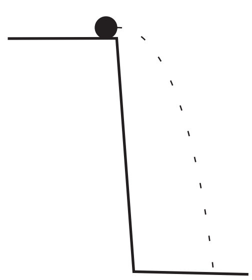


Figure 8.31

6.) A rocket thrusts into deep space far away from any planets or stars and is moving at 7 miles per second. It shuts off its engines.

a.) What happens to the motion of the rocket after shutoff?

- It speeds up gradually.
- It slows down gradually.
- It has a steady speed.
- it has a steady acceleration.
- It stops rather soon.

b.) Is what happens afterwards due to a force?

Explain:

7.) A spherical asteroid (A) as large in diameter as the city of Boston is 100 km from the surface of the Earth. Another asteroid (B) one fourth as massive is 100 km from the surface of the Earth on the other side as shown. Both are stationary.

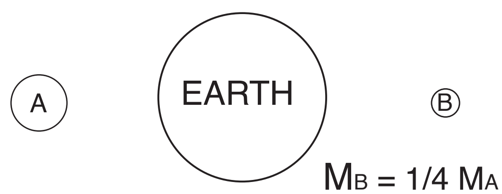


Figure 8.32

a.) Use the masslet model to draw in gravity lines.

b.) What is the ratio of the force of the Earth on A to the force of the Earth on B?

____

c.) Which asteroid has more inertia?_____________________________

d.) Which asteroid is more difficult to accelerate?__________________

e.) How much more difficult?____________________________________

f.) What is the ratio of the two accelerations caused by Earth's gravitational force?______________________

g.) If they both start with zero velocity, which will hit the Earth first?

__________________________ Explain.

UNIT 9

Third Law in Dynamics

UNIT #9 - THIRD LAW IN DYNAMICS

I. OVERVIEW OF THE THIRD LAW IN DYNAMICS UNIT

A. MAJOR PRECONCEPTIONS POSING DIFFICULTIES IN THIS UNIT

1.) When two moving bodies collide, the body moving fastest exerts the largest force.

2.) When two bodies collide, the body with the larger mass exerts the greater force.

3.) Contact forces are not equal when one body accelerates another.

4.) Inertia is a force that is carried by moving objects.

5.) When two bodies collide the harder body exerts the greater force.

6.) When two bodies collide the body that breaks exerts the smaller force.

B. GENERAL STRATEGY OF THIS UNIT

Learning physics is a cumulative process. These lessons rely on knowledge gained and intuitions built in previous lessons in our series. Specifically:

- The molecular model of matter, resulting in the springiness of the surfaces of seemingly "rigid" bodies
- Newton's Third Law in statics
- Some experience with springs
- Inertia as an intrinsic property of matter and not a force

These lessons, like previous lessons in this series, make use of analogies to teach difficult concepts. The instructional strategy is based on anchors introduced in earlier lessons. The unit also employs a variety of other techniques such as student voting, open discussions, collision demonstrations using students, and other laboratory experiments. This variety is built into the lessons to maintain student interest as the teacher carefully works to unpack their interwoven set of preconceptions.

The overall goals of these four lessons are to help students achieve an understanding of Newton's third law (especially during collisions) and to relate this law to the conservation of momentum. Clinical interview and diagnostic test data indicate that many students harbor a general naive view of force as an acquired or innate property of single objects, rather than that of forces arising from an interaction between objects. Thus some students view objects as inherently more "force-full" by virtue of their mass, speed, hardness, etc.

It is in some ways appropriate that this, the last, unit in this series should deal with some of the most firmly entrenched preconceptions students have. The third law causes students a great deal of difficulty in both static compression situations (Unit 1) and in static tension situations (Unit 4). The inertia concept introduced in Unit 7 also aids in a deeper understanding of the nature of force as understood by physicists. We must approach the list of preconceptions above with great care recognizing that we have added the complexity of motion to the interactions we wish to study.

This suggests that Newton's third law, which makes explicit the relational quality of forces, may play a more important role than it is ordinarily granted. If students acquire a deep understanding of the third law, they may be much less apt to have difficulty with both quantitative problems requiring the identification of reaction forces and qualitative problems, such as those drawing out the "impetus" preconception, in which many students view force as a property of a moving object causing it to move with constant velocity.

The lessons on Newton's third law proceed from simple to more complicated applications; from static to dynamic examples; and within dynamics from cases where the interacting bodies are equal in mass to where they are unequal in mass. Our aim is to help students build (or reinforce) intuitions first in simple cases, then to extend their intuitions to more general cases.

Teachers have found it advantageous to spend at least four class periods on this unit. While this is a major time commitment, a number of teachers feel the time spent on these lessons has been very helpful developing a solid intuitive sense about Newton’s third law as applied in dynamic situations.

C. <u>**THE PHYSICIST'S VIEW**</u>

Research demonstrates that many students hold the following strong and *incorrect beliefs* about colliding objects:

- When a moving object collides with a stationary one, the moving one exerts a greater force and the one at rest feels a greater force
- If both objects move, the more massive object exerts a greater force and the less massive one feels a greater force.
- Hard objects exert larger forces than soft objects.
- Rigid objects exert larger forces than fragile objects which break.

These preconceptions are very deeply rooted and interconnected so they must be sorted out with great care. Students may envision the unequal *results* of a collision between big and small cars, and confuse force (as defined in physics) with its effects. These lessons, among other things, aim to help students make that distinction between a force exerted and the effect of that force. Students also tend to confuse *forces exerted* by a body and *forces felt* by the same body. When you bring up the problems in these lessons, you must be very clear as to what forces you are asking about.

In working through this unit, students will begin to struggle with one of the most common and persistent of preconceptions: that a moving object *has* a force, which it carries along and gives up when it collides with another object. This idea is not only common among students, but has counterparts in the views of the natural world commonly held before Galileo. It is part of what is known as the "impetus" model, widely believed by students and lay people.

As is true with most naive beliefs, there *is* something potentially useful which we can help bring to the surface. Moving bodies don't have force, but they *do* have momentum, and they do give up some of their momentum in a collision or other interaction. The last part of this lesson makes the connection between Newton's third law and the conservation of momentum.

It took many centuries for physicists to figure out the distinctions between inertia, force, momentum, and energy. We should not be discouraged if it takes students some time as well, especially since each of these terms carries many connotations from everyday language.

II. THIRD LAW IN DYNAMICS – LESSON 1

A. OVERVIEW OF THE LESSON

The target problems in this lesson involve objects of equal mass, with unequal masses considered in Day #2. The Anchors are the cases of one or two springs held between the hands. Many students latch on to the idea of the massless spring as a "force equalizer", exerting equal outward force on both ends when compressed. As in previous lessons, bridging analogies and models are proposed to help students see the analogy between the anchor and the target problem.

In this lesson (and also in Day #2), demonstrations are used that have students riding on rolling carts (or rolling chairs) holding bathroom scales. These demonstrations have proven to be very motivating. As always, in labs and demonstrations, it is important to make students think in advance about what will occur and to make predictions, even if only to themselves. The observation of a demonstration is most valuable if each student has consciously thought about the situation and made predictions that will be confirmed or disconfirmed. It is also important to discuss the results afterward by asking students to explain *why* the forces were equal, rather than just memorizing the *fact* that they were equal.

It is very helpful if both non-digital bathroom scales are of the *same make and model.* The students are taking on-the-fly readings of forces using a scale designed for static measurements. All good scales would presumably read static forces accurately, but different kinds of scales may have different damping and therefore give different dynamic readings. If you cannot find identical scales, see the Teacher Notes for a suggestion about the use of foam blocks instead. The approximately equal scale readings or the roughly equal foam compression will be sufficient to surprise students who expect very unequal forces, and lead them to examine their preconceptions.

B. MATERIALS

1.) dynamic carts (one with plunger)

2.) one bed spring

3.) one pair similar springs

4.) one pair different springs

5.) two rolling carts, or rolling chairs

6.) two non-digital bathroom scales or mounted foam blocks (see Figure 9.11).

C. OBJECTIVES

1.) The student should begin to make sense of the notion that forces between touching bodies are equal and opposite at each instant during an interaction between bodies of equal mass.

2.) The student should understand that forces on the two ends of a spring of negligible mass are equal even if one or both ends of the spring are in motion.

D. **CONCEPT DIAGRAMS - THIRD LAW IN DYNAMICS - DAY #1**

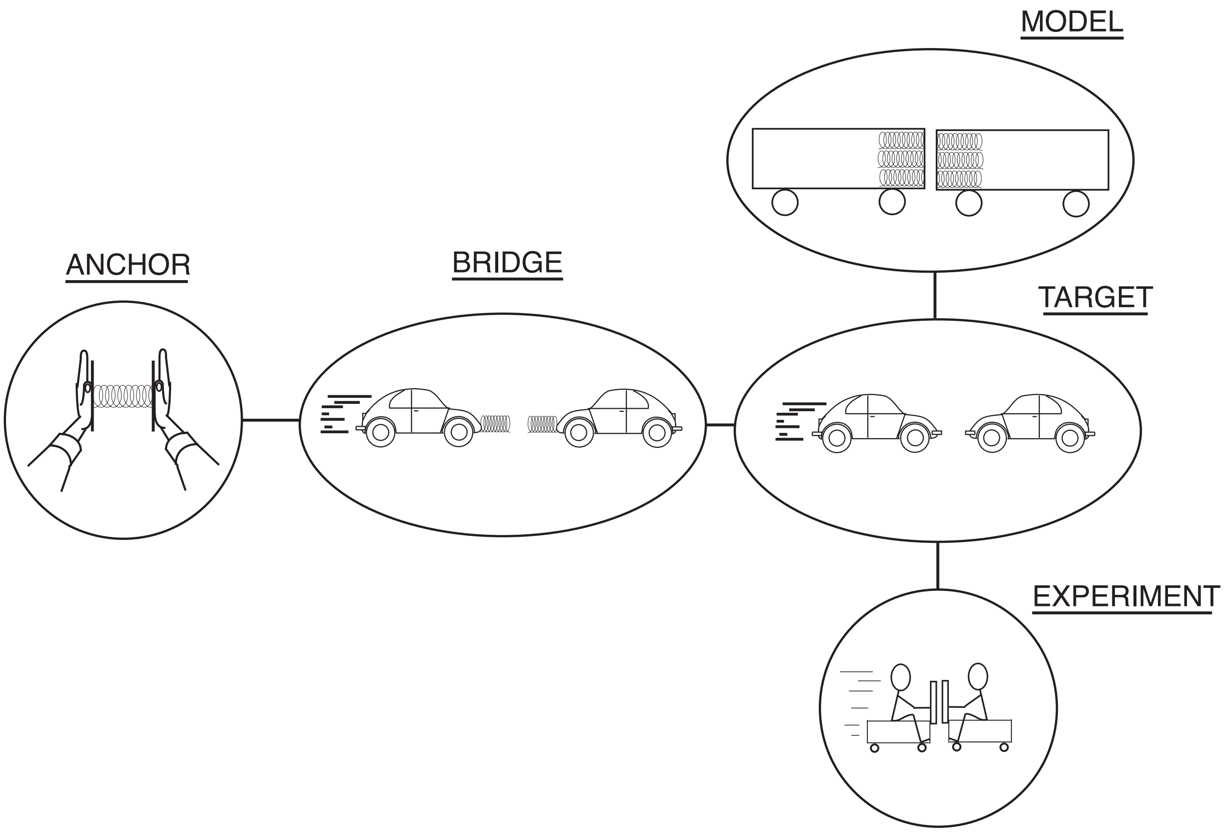


Figure 9.1

E. LESSON PLAN - THIRD LAW IN DYNAMICS - DAY #1

1.) Introductory remarks

We have been studying forces between touching objects. But today we will examine touching objects that are also moving. We usually refer to these situations as explosions or collisions.

2.) Vote #1 on carts with one exploding spring

a.) Introduction

Before the vote, it is advisable to take the plunger out of the dynamics cart to show it is simply an extension of a spring, and that the spring is enclosed to keep it from wobbling. Also, point out that the carts have equal mass, even though one has a spring attached.

b.) Draw Figure 9.2 and explain it but do not demonstrate the explosion. The demonstration is called for in part 4 of this lesson.

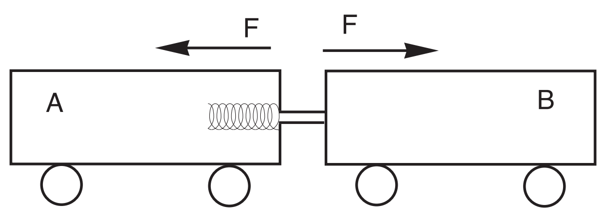


Figure 9.2

c.) The question - Vote #1

Which force is greater during the explosion?

- The force exerted *on cart A* with the spring
- The force exerted *on cart B* without the spring
- The forces exerted on the carts are equal

d.) During the discussion

- Try to draw out students with differing opinions. If students do not propose the ideas in Figure 9.3, the teacher may introduce them as competing models.
- In the hanging spring model both forces must be equal by symmetry as the spring is not attached to either cart.
- Students who find the uneven expansion model appealing should be confronted to explain how the spring behaves this way.

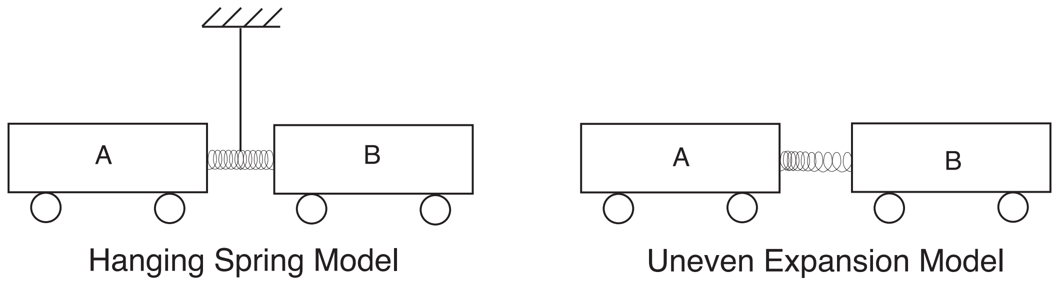


Figure 9.3

3.) <u>Presentation of the anchor situation</u>

a.) Draw Figure 9.4 and demonstrate the hands holding the bed spring compressed.

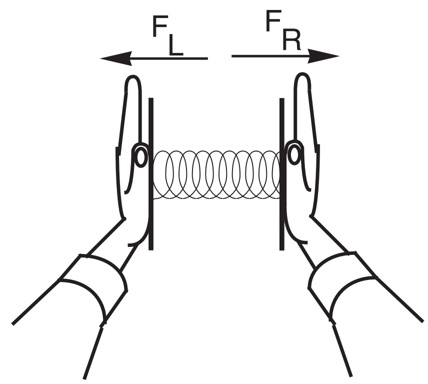


Figure 9.4

b.) Ask for a **public vote** on the question.

While holding the spring in a **compressed, static situation**, which force is greater?[1]

- $F_{\text{spring on the left hand}}$
- $F_{\text{spring on the right hand}}$
- These forces are equal

c.) Discussion

Ask students to compare this anchor situation with the exploding carts situation, back in vote #1.

How are they similar? How are they different?

---

[1] Try to arrange the spring so it is initially attached to one hand before it is compressed.

4.) Cart explosion demonstration

a.) After the discussion of the exploding carts and the anchor (above), perform the exploding carts demonstration to show the dynamics carts separate with equal speeds. In order to maintain interest, *perform the demonstration only after the discussion* of the models and the anchor.

b.) Discuss the demonstration

It may help some students to talk about the explosion in detail, for instance, looking at several moments while the spring is expanding and discussing the forces on each of the carts.

5.) Presenting the new target problem - collision of equal masses

a.) Draw the picture of the twin cars colliding with one moving and one stationary.

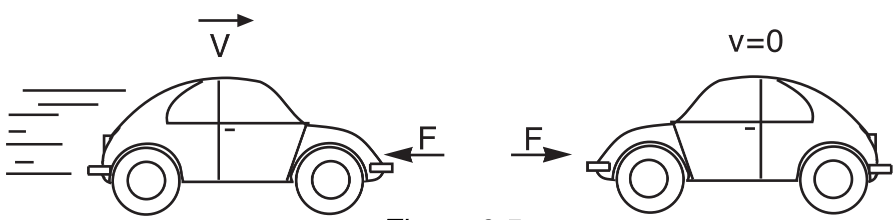


Figure 9.5

b.) Question - Vote #2

On which car is a greater force exerted?

- On the moving car
- On the stationary car
- An equal force is exerted on each car

c.) Discussion of the vote as necessary

6.) Present the anchor situation

a.) Draw the figure below and **demonstrate** the two hands pushing on two springs with a board between them. Point out to the class that the right hand is not moving.

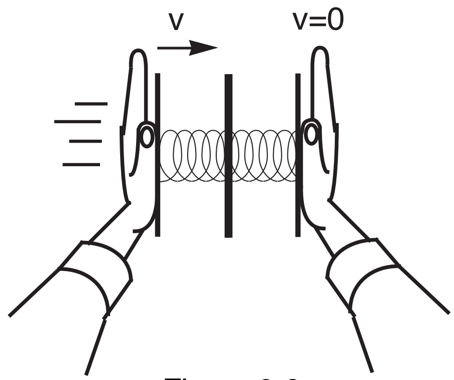


Figure 9.6

b.) Discussion question about compression

Which spring compresses more?

- Spring on moving hand
- Spring on stationary hand
- Both springs compress the same amount

c.) For emphasis, demonstrate again moving only one hand showing the two springs compress equally.

d.) Introduce the discuss question about forces.

On which hand is a greater force exerted?

- On moving hand
- On stationary hand
- The same force is exerted on both hands

e.) Challenge question

If you feel more interaction is needed, challenge the group with the questions: *Why does equal make sense? How can the springs adjust to push equally?* Confirm the correct answer and review the idea of the springs as "automatic force equalizers."

7.) <u>A bridging example - thought experiment</u>

a.) Draw Figure 9.7 and describe the situation showing a moving car with a spring hitting a stationary car with a spring.

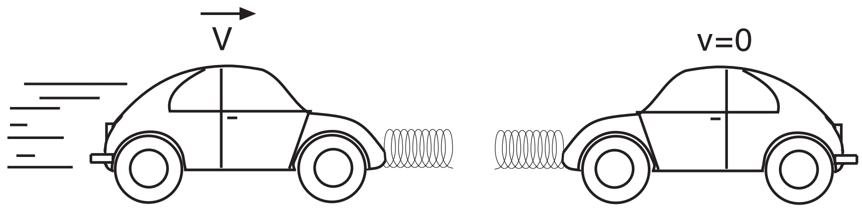


Figure 9.7

b.) Question - <u>Vote #3</u>

Which spring compresses more?

- Spring on the moving car
- Spring on the stationary car
- Both springs compress the same amount

c.) Discuss the vote as necessary

8.) Present the collision of hard carts

a.) Demonstrate crashing a hard dynamics cart into a stationary hard dynamics cart.

b.) Question - <u>Vote #4</u>

On which car is a greater force exerted?

- On the moving car
- On the stationary car
- The same force is exerted on both cars

c.) Comparison questions to discuss

- How does this situation compare with the anchor (spring between hands)?
- How does this situation compare with the target (cars colliding)?

9.) Introduce the microscopic model for rigid carts

a.) Draw the picture of carts with "small springs inside between the atoms."

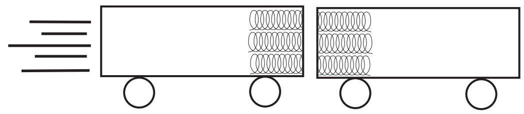


Figure 9.8

b.) Compare the microscopic model with the target problem.

Discuss the comparison as needed.[2]

10.) Demonstrate colliding equal-mass students[3]

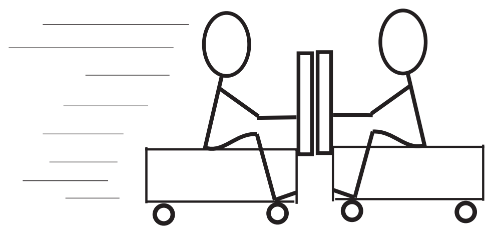


Figure 9.9

a.) Use rolling chairs or carts for students to sit on. (See Teaching Note #7)

b.) Select two students of approximately equal mass.

c.) Explain that you are going to push one student so he/she will be coasting at the moment of collision with the other student (who is stationary before the collision). Carefully instruct the two students to sit on the carts properly so they do not get injured.

d.) Have an extra student look over the shoulder of each rider to estimate the maximum scale reading. (The teacher should push the moving cart/chair to produce a safe speed.)

e.) Repeat the experiment enough times so most class members are convinced that there is not a pattern of one scale reading higher.

[2] It may be helpful here to introduce the ratchet spring (see Teacher Notes for Day #3) as a better model than the regular spring for something that is irreversibly damaged (broken or dented) in a collision.
[3] If you are short of time, it is possible to set up the demonstration and then run out of class time leaving students to worry about what will happen until the next class.

f.) It is helpful if students absorb some of the impact by bending their elbows so the maximum scale reading lasts long enough to be estimated.

g.) Exchange scales if one reads systematically higher.

11.) Important review step

Have each student write an explanation using the terms spring and compression for how the forces could be equal in the demonstration (or in the target, if unable to do the demonstration).

12.) Assign homework

a.) Homework - Third Law in Dynamics - Day #1

F. TEACHING NOTES - THIRD LAW IN DYNAMICS - DAY #1

1.) Pay careful attention to the distinction between "force exerted" by one body as compared to the "force felt". If you have trouble try the following ideas:

a.) Have a student stand up and tell him/her to duck as you gently simulate trying to punch but miss. Ask about the force exerted and the force felt and try to draw out the idea that *contact* is necessary.

b.) Have each student push on a neighbor's shoulder with a finger and notice that the finger bends. How can you "exert" a force without feeling a force?

2.) The issue of unequal masses may be introduced by students, but it is best to defer the issue. Promise that the issue will be dealt with soon.

3.) A relative motion argument may be helpful to compare a symmetrical situation with one that seems asymmetrical. It is suggested that this approach will only be helpful to students who deal with abstraction easily. Thus, the item is included as a more challenging homework problem.

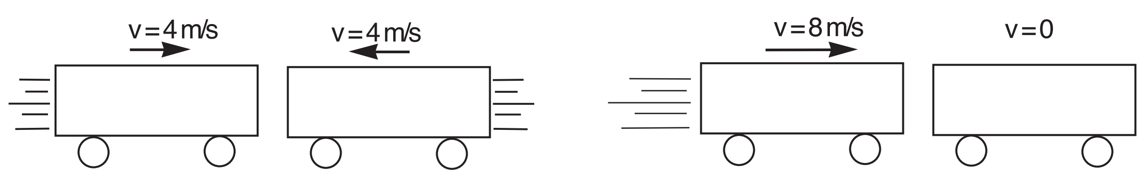


Figure 9.10

4.) Some students may be concerned about the situation in which "one cart hits the other really hard". While the problem of "impetus" or "force of motion" may be hidden in this concern, it is suggested that the teacher treat a hard hit as a way to exert a large force. The notion of impetus should be clearly confronted by reminding students that inertia is not a force. The matter is reviewed in the Day #3 lesson.

5.) The concept of the spring as a force equalizer during acceleration may need careful attention in some cases. The assumption here is of a massless spring which compresses instantly and evenly with no "shock wave". Because the spring is massless, it requires no net force to accelerate it, and so the force on each end of the spring will be equal, even if the spring is accelerating. Some advanced students may be able to consider on their own the concept of an accelerating spring with mass, but most students will not be concerned with this.

6.) When reconsidering the hard cart problem, it may help some students to recall that the layer of atoms that are "touching" on the hard carts have very little mass compared to the rest of the cart so we can think of these as massless springs.

7.) For teachers who would prefer to use foam blocks, instead of bathroom scales, Figure 9.11 shows one arrangement. Open cell foam such as rug padding can be glued together to form a block about 8 inches thick. The edges of the plywood must provide space for students to hold the apparatus. The colored paper surface or magic marker coloring the edge should make the interface between the two blocks easy to observe during the collision. If the plywood is backed up by the cart frame as well as the student's hands, the arrangement is more stable. Although the foam provides only qualitative results, we find that the foam block arrangement avoids much of the technical difficulty of working with bathroom scales to get quantitative results.

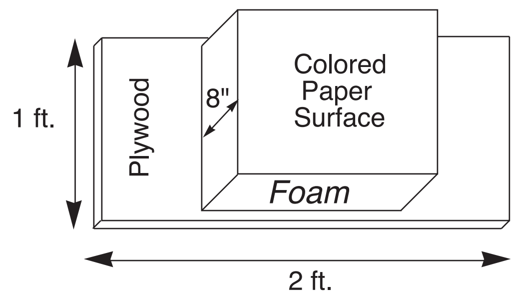


Figure 9.11

8.) Some teachers with Microcomputers Based Lab (MBL) equipment may be tempted to insert a demonstration of equal mass carts, with force probes, near the end of this lesson. We urge you to resist the temptation and hold such a demonstration during the Day #3 lesson with the case of unequal masses.

III. THIRD LAW IN DYNAMICS – LESSON 2

A. OVERVIEW OF THE LESSON

This lesson is designed to start with a review of the homework to begin to firm up student thinking about the ideas introduced in the first day's lesson. Then the major activity of Day #2 is presented. Students will work in small groups to study a series of collisions and reflect on how those collisions take place by completing worksheets. The worksheets are designed to view each collision as five "snapshots" to help them think of a collision as an interaction that takes a finite amount of time. This slow motion view of a collision helps students visualize how the forces and velocities change during an interaction that students once perceived as instantaneous. This is an example of a qualitative laboratory where the purpose of the materials is not to provide numerical data, but to provide "food for thought" as a focus for explanatory arguments and discussion. Such discussions are essential for fostering conceptual change in the presence of conflicting preconceptions.

B. MATERIALS

1.) Collision Analysis Activity Sheets

2.) two dynamic carts per group (one with spring)[4]

3.) two bricks per group

4.) rulers

C. OBJECTIVES

1.) The student should understand that an interaction (collision) between two bodies occurs during an extended finite amount of time.

2.) The student should be able to think about how the velocities of both objects and the forces between objects are continually changing.

3.) The student should be able to make sense of the idea that in the mid-point of a collision when the spring is at maximum compression, the forces reach maximum value and the instantaneous velocities of both objects are equal.

4.) The student should understand that the force of A on B is equal to the force of B on A at every instant during a collision.

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[4] See Teaching Notes #6.

D. LESSON PLAN - THIRD LAW IN DYNAMICS - DAY #2

1.) Review the homework from Day #1

a.) Give careful attention to the matter of a hard object striking a soft object by reviewing the example of a strong spring against a weak spring. Recall the "automatic force adjustment" feature that enables strong and weak springs to provide equal and opposite forces.

b.) Breaking objects are a most troublesome problem and deserve genuine understanding and patience from the teacher, for these cases are very counter intuitive. Talk through such a collision in slow motion indicating how the forces build up in an equal and opposite fashion until the moment one object breaks. It is important for students to recognize that both forces then rapidly drop to zero.

2.) Introduce the Collision Analysis Activity

a.) Pass out the activity sheets and introduce the activity. Demonstrate the spring nature of the plunger in the carts.

b.) Urge students to try each collision to see what happens, and then ask them to go through the collision in slow motion. Encourage students to focus on the spring nature of the plunger.

c.) Emphasize the need to follow the directions and especially try to construct neat vectors of appropriate lengths using a ruler and pencil, so corrections can be easily made.

3.) Small group work on the Collision Analysis Activity

a.) During the activity it is important for the teacher to circulate among the groups looking for some of the following common problems:

- Many students believe the second cart does not move until the first one stops. Watch for this problem and other examples where there is a force but no resulting change in velocity. You may inquire "if there is a force, why doesn't the velocity change?"
- Watch also for changes in velocity when there is no force.
- Check for changes in velocity of one cart without some change in velocity of the other.

4.) Assign homework

a.) Neatly complete the Collision Analysis Activity if not finished in class.

b.) Homework - Third Law in Dynamics - Day #2

E. TEACHING NOTES - THIRD LAW IN DYNAMICS - DAY #2

1.) During the Collision Analysis Activity it is important for each group to have have a pair of carts so they can work through each case in slow motion by moving the carts with their hands as they talk their way through the collision.

2.) While the Collision Analysis Activity is suggested here as the second lesson of the set, it is also very effective following the Day #3 lesson.

3.) If this activity is conducted as Day #2, the teacher may need to be flexible about expecting all answers to be correct this early in the unit. It would be possible for students to hold their lab activity sheets an extra day to allow more time to reflect on their answers and correct trouble spots.

4.) If the homework review takes more time than planned and there is only a little time at the end of class, it is still very helpful to have students do the equal mass case (first page) of the Lab Activity so they have some idea about how to approach the homework. The unequal mass collisions can be investigated in the laboratory after the Day #3 lesson.

5.) The Collision Analysis Activity uses springs in all of the collisions. Some students may ask about collisions without springs. The teacher should plan to decide how to deal with this problem when it arises. The matter could be deferred until later when inelastic cases are considered by the whole class.

6.) Dynamics carts equipped with springs are preferred due to the tangible nature of the spring. However, carts equipped with magnets can be substituted, provided there is an explanation to help students visualize an analogy between springs and magnets.

IV. THIRD LAW IN DYNAMICS – LESSON 3

A. OVERVIEW OF THE LESSON

This lesson first aims to generalize the results of the lesson in Day #1 to the case of unequal masses. To prevent students from accepting too readily a "correct" answer that they don't truly understand, the lesson calls for consideration of a collision between two humans - one very large and one very small. Coming to terms with this example will go a long way toward helping them understand Newton's third law in the dynamic case. The lesson also calls for careful consideration of the "equivalent spring" concept of the force on two carts colliding as an alternative to the "impetus" conception of force. Throughout the lesson, it is important to challenge students who seem to simply accept equal forces as the correct answer without struggling with these concepts. Finally, the lesson moves on to introduce momentum as a useful concept to replace the "impetus notion of force" so strongly believed by most students.

B. MATERIALS

1.) dynamics carts (one with a spring) and bricks or books

2.) one bed spring

3.) one pair of different springs in series

4.) two rolling carts or rolling chairs

5.) two bathroom scales or foam blocks on plywood

6.) (optional) Create slow motion video or computer simulation of two carts colliding with a spring between them.

7.) (optional) Force probs on two carts may be used to display the graphs of force vs. time for a collision of unequal masses. This demonstration is suggested as an option in the later part of the lesson.

C. OBJECTIVES

1.) The student should understand that the third law applies throughout a collision, even for the case of unequal masses or unequal damage.

D. CONCEPT DIAGRAM - THIRD LAW IN DYNAMICS - DAY #3

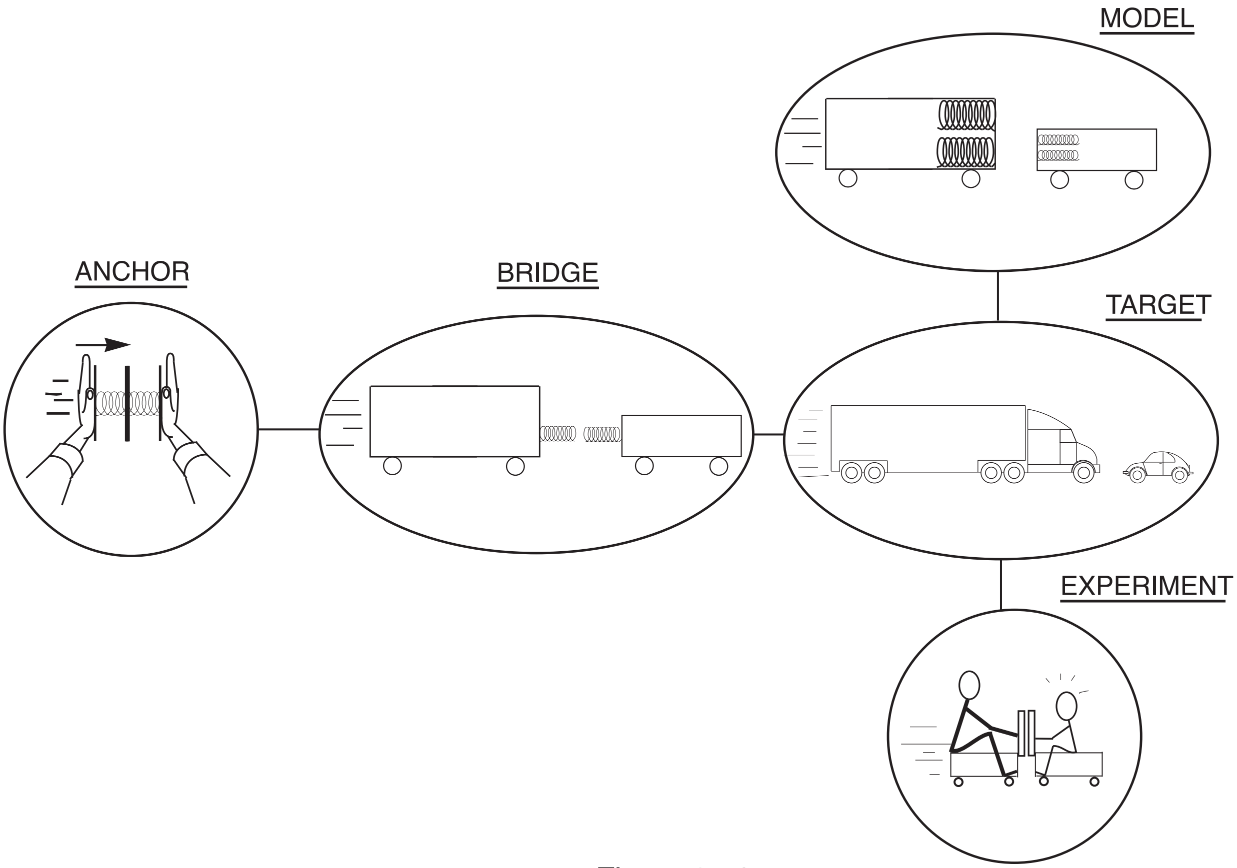

Figure 9.12

E. LESSON PLAN - THIRD LAW IN DYNAMICS - DAY #3

1.) Review homework questions

Briefly review the homework from the previous lesson as appropriate. Projected images of collision activity sheets and homework sheets, showing acceptable answers, will save some time.

2. Introduction of collisions with unequal masses

a.) Explain that today's class is going to examine the forces between moving objects that have unequal mass.

b.) Present the target problem as shown in Figure 9.13.

Your broken-down car has come to a halt on the shoulder of the highway. You stand and watch as the big truck proceeds to smash into your car at 40 mph.

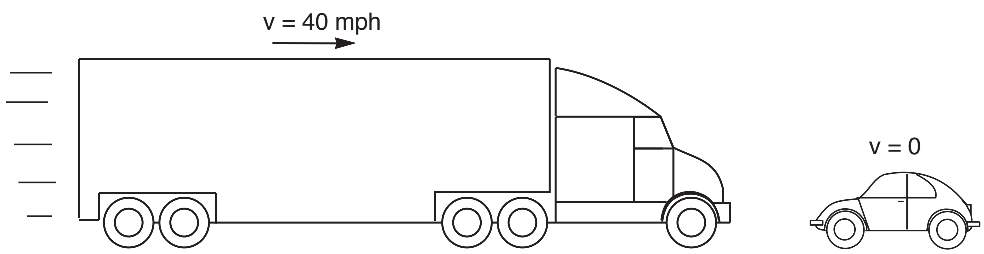

Figure 9.13

c.) The question - Vote #1 (Pair voting suggested)

On which vehicle is the greater force exerted?[5]

- $F_{\text{Truck on Car}} > F_{\text{Car on Truck}}$
- $F_{\text{Truck on Car}} < F_{\text{Car on Truck}}$
- $F_{\text{Truck on Car}} = F_{\text{Car on Truck}}$

d.) Be sure to record your makes sense score.

e.) Discuss student reactions.

Aim for maximum controversy without closure at this time. Keep this discussion brief as the rest of the lesson should help with their difficulties.

---

[5] If the teacher prefers a concrete target example instead of the big truck, one can demonstrate a heavily loaded dynamics cart colliding with an empty dynamics cart for the first vote.

3.) Presentation of an anchor and a bridge

a.) Introduce the anchor below from the earlier lesson.

- Draw the anchor diagram (Figure 9.14)
- Review and demonstrate the fact that both springs compress equally even when only one hand moves.

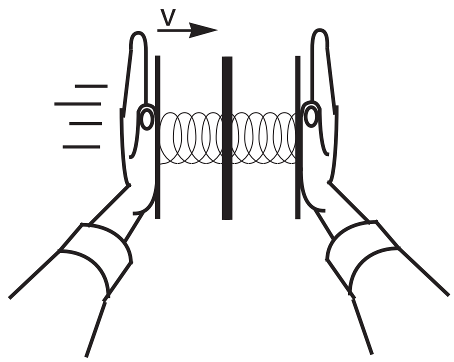

Figure 9.14

b.) Draw the bridge example below (Figure 9.15) showing colliding carts of *unequal* mass with springs attached to *each*.

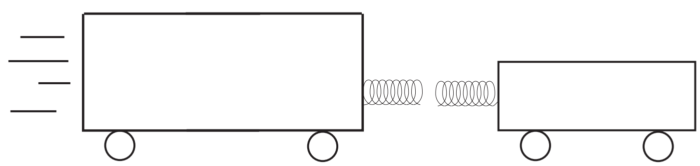

Figure 9.15

c.) Ask students to compare the bridge (Figure 9.15) to the big truck problem. How are they the same and how are they different?

4.) Discuss unequal damage and malleability or "crushability" issue[6]

a.) Acknowledge that the car is damaged more. Ask "which (car or truck) would be damaged more by an equal sledge hammer blow?"

b.) Differentiate damage from force exerted and introduce malleability as a factor influencing damage.

c.) This would be a good point to discuss the ratchet spring model (see Teaching Notes #4) or mention it again if it has already been discussed, since this provides a bridge between the spring model and permanent damage in a collision.

5.) Review the unequal stiffness issue - Vote #2

a.) *Demonstrate*: hands compressing two springs of unequal stiffness (see Figure 9.16).

b.) Equivalent springs question - Vote #2

On which hand is the greater force exerted?

- Left
- Right
- Equal

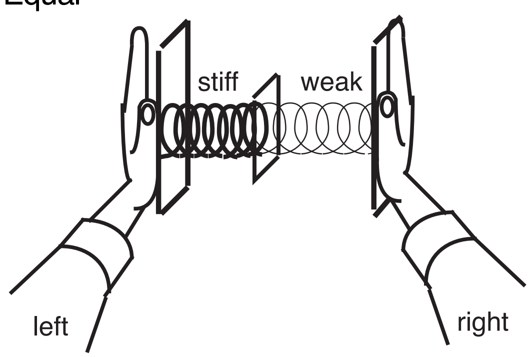

Figure 9.16

c.) *Challenge* the class with the question.

"How could these forces possibly be equal?"

d.) Review the idea that two different springs can automatically self-adjust to provide equal forces.

Include the equivalent spring argument in the discussion, that during the compression, the two springs can be considered as a single, equivalent spring.

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[6] Discussion of this section may be postponed until after the major demonstration in part 6 below.

6.) <u>Major demonstration: student collision with unequal masses</u>

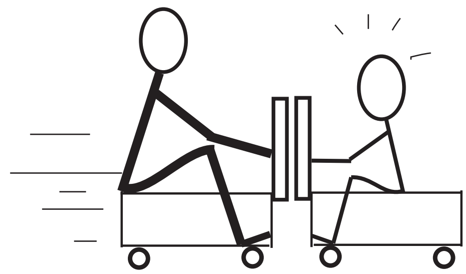

Figure 9.17

a.) Use the rolling carts or chairs again for a student collision. Make a big deal of selecting students of very different mass by inviting the largest and smallest student in the class.[7]

b.) Ask the class to predict the results. Explain that you are going to push the massive student so she/he will be coasting at the moment of collision with the small student at rest.

c.) Demonstrate the collision three or four times comparing the forces exerted on each student.

d.) When much of the class seems to be leaning in the direction of believing that the forces could be equal it is time to *challenge* their position.

Challenge the idea that the forces could be equal with the extreme case of a huge football player running fast colliding with the outstretched arm of a small middle school student. *How could the forces possibly be equal?* (Draw Figure 9.18).

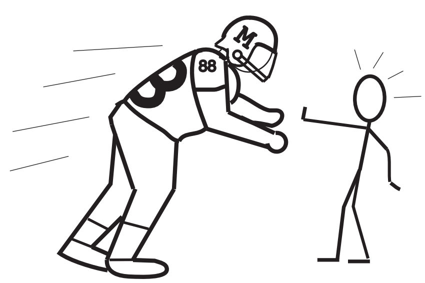

Figure 9.18

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[7] Details of this demonstration may be reviewed in the equal mass demonstration part of the Day #1 lesson. Be sure both students are carefully instructed about how to position themselves so their feet, knees, and fingers are not injured.

e.) Discussion as needed.

This example is very counter intuitive for many students. They need to struggle with it.

f.) Follow up questions:

Do we get equal forces in the big truck example?

What are *alternative explanations to unequal forces for why the small car is damaged more?*

g.) Optional Demonstration with force probes

Demonstrate the collision of unequal masses especially the large moving mass striking the stationary small mass cart.

7.) Assign homework

a.) Homework - Third Law in Dynamics - Day #3

b.) Complete any parts of the Collision Analysis Activity that were not finished earlier.

F. TEACHING NOTES - THIRD LAW IN DYNAMICS - DAY #3

1.) The dynamic third law can be especially troublesome, and this lesson should allow time for students to struggle with these ideas. It is probably best to allow plenty of time to struggle with the concepts in the heart of the lesson.

2.) The teaching notes at the end of Day #1 may be helpful, as some of these issues are likely to turn up during Day #3.

3.) Careful consideration of the equivalent spring concept seems to be important, so that students are allowed to struggle with why the forces are equal, rather than just trying to memorize the results of the demonstration with the students on the carts.

4.) If the question of the elasticity of a collision arises (e. g. the balsa wood bumper problem or the wad of clay hitting the cart problem), it may be helpful to discuss a collision with a ratchet spring, in which the spring compresses, but does not subsequently decompress because of some ratchet action. Such a collision would be completely inelastic, and the two colliding carts would move off at the same speed. This is very similar to the wad of clay, or the small car, which compress during the collision to bring the objects to the same speed, but do not then decompress to send the colliding objects off at different speeds. This ratchet spring model may help students who have trouble seeing objects which break during a collision as analogous to springs which spring back to their original shape.

5.) Teachers are strongly advised to add variety to the voting style of these lessons. Pair voting may be a good option for this lesson.

V. LESSON PLAN - THIRD LAW IN DYNAMICS – DAY #4

A. OVERVIEW OF THE LESSON

This lesson begins with the use of slow motion video created for the Day #4 lesson based on the collisions pictured in Figures 9.23 and 9.24. Pause techniques are used to review the important aspects of earlier work in the unit. Following the introduction, the impetus concept is confronted through a vote and then a discussion. This work is wrapped up by suggesting that momentum is a useful idea to use instead of the "force of motion" concept.

The teacher may choose to omit the video review and the impetus discussion in order to move directly to the introduction of momentum in part 4 of the lesson.

The final section of the lesson formally introduces the momentum concept, and moves on to derive the momentum conservation relationship starting with the dynamic third law (equal forces). The lesson then finishes with discussion and demonstration examples to help students relate intuitively to the momentum concept. The goal here is to help students see that momentum conservation makes sense (for many people) even though the equal force idea may be very troublesome.

B. MATERIALS

1.) two dynamics carts with spring plungers

2.) two bricks

3.) video or computer simulations of collisions. (Optional)

C. OBJECTIVES

1.) The student should understand that moving objects do not exert forces on each other before or after a collision.

2.) The student should understand that momentum is a useful concept to measure an objects ability to exert a force on the other objects during a collision.

3.) The student should be able to show how the dynamic third law leads easily to the notion of conservation of momentum during a collision.

D. CONCEPT DIAGRAM - THIRD LAW IN DYNAMICS - DAY #4

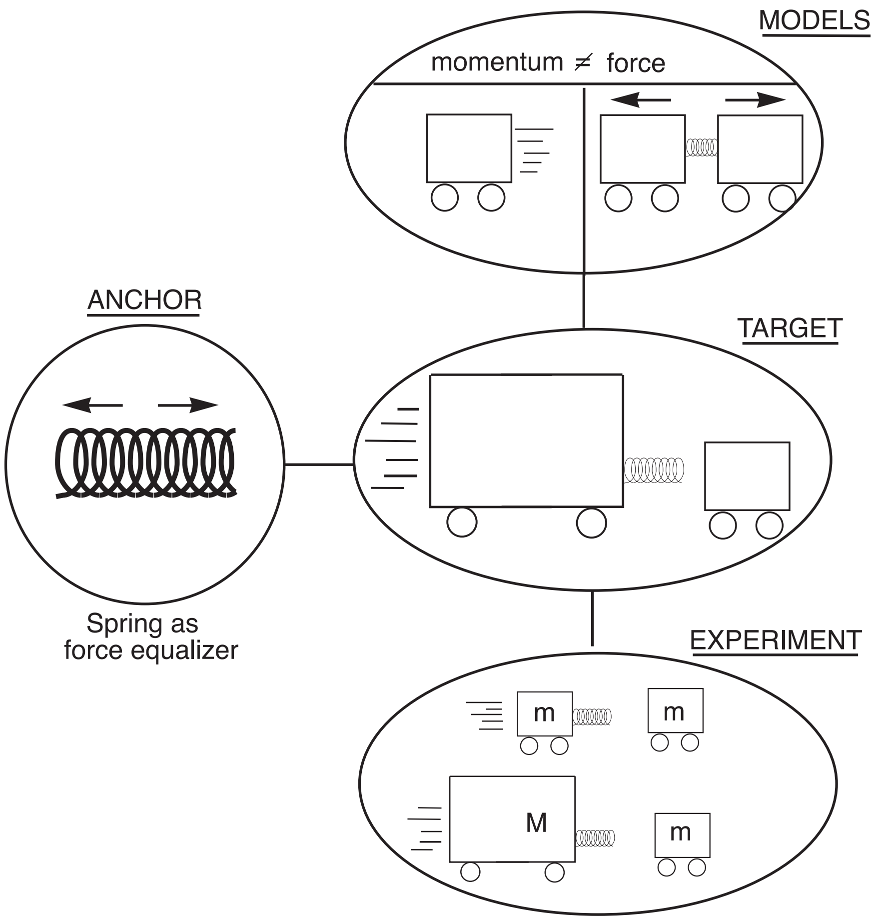


Figure 9.19

E. LESSON PLAN - THIRD LAW IN DYNAMICS - DAY #4

1.) Review the homework from Day #3

2.) Video analysis of equal mass collision[8]

a.) Play back the video with pauses during the collision.

b.) Point out the equal and opposite compressions.

c.) Point out that the stationary cart starts moving before the springs are completely compressed.

d.) Review the fact that the springs are "automatic force equalizers" and these forces would be equal *even* if the springs were different.

e.) Review the idea that we can still think of springy molecules in the strong big truck, which only dents a little when it wrecks the small car.

3.) Confronting the "impetus notion" - Vote #1

a.) The question - Vote #1

How much force does the big truck exert on the small car before they touch?

- A little
- A lot
- None

b.) Challenge question

Probably a lot of people will vote for no force when the carts are not in contact, so *confront* them with a question: "If a flying ball has no force, what makes you afraid of being hit in the side of the head by a high speed pitch?"

[8] See Teaching Notes # 1 and Figures 9.24 and 9.25.

c.) Discussion

Try to draw out the explanation that the ball has momentum, but not force, while in the air. The forces arise only when the spring-like molecules in the surface of the ball compress against the spring-like molecules in the surface of your head. These forces are equal--one hurts your head, and the other stops the ball.

4.) Formally introduce momentum

a.) After some struggle, assure the class that the moving ball has an important property that gives it the potential to hurt if it hits you. That important property is called *momentum,* not force. This momentum, which determines how much the ball will hurt, depends on:

- Mass
- Velocity (with respect to my head)

b.) Define momentum- a vector quantity

momentum = (mass) x (velocity) is a proper definition.
Symbolically:

$$\vec{p} = m\vec{v}$$

c.) Discuss changing momentum.

Symbolically:

$$\Delta\vec{p} = m\,\Delta\vec{v}$$

5.) Discuss and derive momentum relationship for collisions

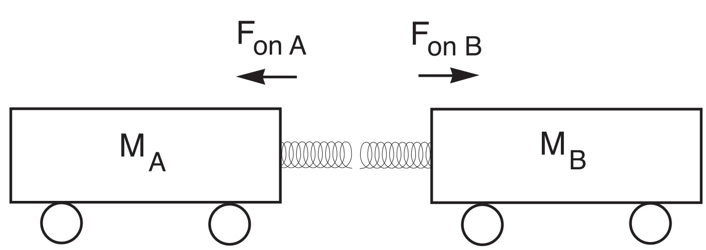


Figure 9.21

The force values in this derivation are average forces during the collision.
If the forces are equal and opposite at each instant, the average forces must be equal and opposite.

a.) $\vec{F}_{on\ A} = - \vec{F}_{on\ B}$

b.) $\Delta t_A = \Delta t_B$

c.) $\vec{F}_A \Delta t_A = - \vec{F}_B \Delta t_B$

d.) Recall $\vec{F} = m\vec{a}$

thus $\vec{F} = m \Delta \vec{v} / \Delta t$

and $\vec{F} \Delta t = m \Delta \vec{v}$

e.) $m_A \Delta \vec{v}_A = - m_B \Delta \vec{v}_B$

f.) Notice this indicates that the momentum one cart gains equals the momentum the other cart loses.

$$\Delta \vec{P}_A = - \Delta \vec{P}_B$$

6.) <u>Discussion</u>

a.) Ask if anyone can think of a simple example or analogy that shows how the above relationship makes sense.

b.) If little response, consider asking:

- What if the carts are 5 kg and 10 kg, how would the changes in velocity compare?

- How could you state the meaning of the formula in words?

("The amount of momentum gained on one side is equal to the amount lost by the other side in an interaction")

7.) Demonstrate two collisions

a.) equal masses

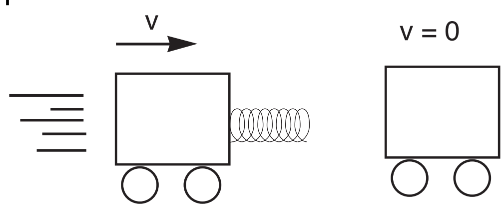


Figure 9.21

b.) unequal masses

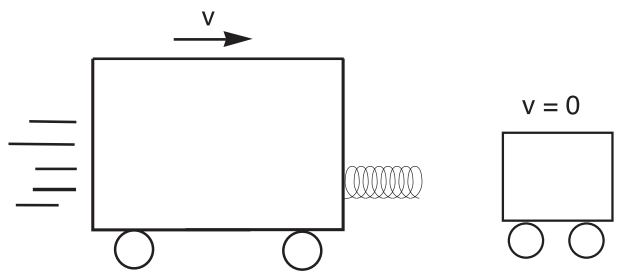


Figure 9.22

8.) Summarize with generalizations from the class about changes in momentum

9.) Review the original big truck question - Vote #2

a.) The question - Vote #2

The big truck going 40 mph hits your parked small car. On which vehicle is the greater force exerted?

- $F_{T \text{ on } C} > F_{C \text{ on } T}$
- $F_{T \text{ on } C} < F_{C \text{ on } T}$
- $F_{T \text{ on } C} = F_{C \text{ on } T}$

b.) Emphasize the importance of the makes sense score on this vote.

10.) Following the discussion the teacher might include a third vote comparing the magnitude at the two accelerations during the collision.

11.) Assign homework

Homework - Third Law in Dynamics - Day #4

F. TEACHING NOTES - THIRD LAW IN DYNAMICS - DAY #4

1.) The video tape work called for early in this lesson provides an interesting review and confidence building experience for students. Pausing the video during the collision provides an excellent chance for students to see that the springs are equally compressed, and thus the forces are equal. The plunger on the dynamics carts must be clearly marked and the two springs should have the same spring constant. See the details in Figures 9.23 and 9.24.

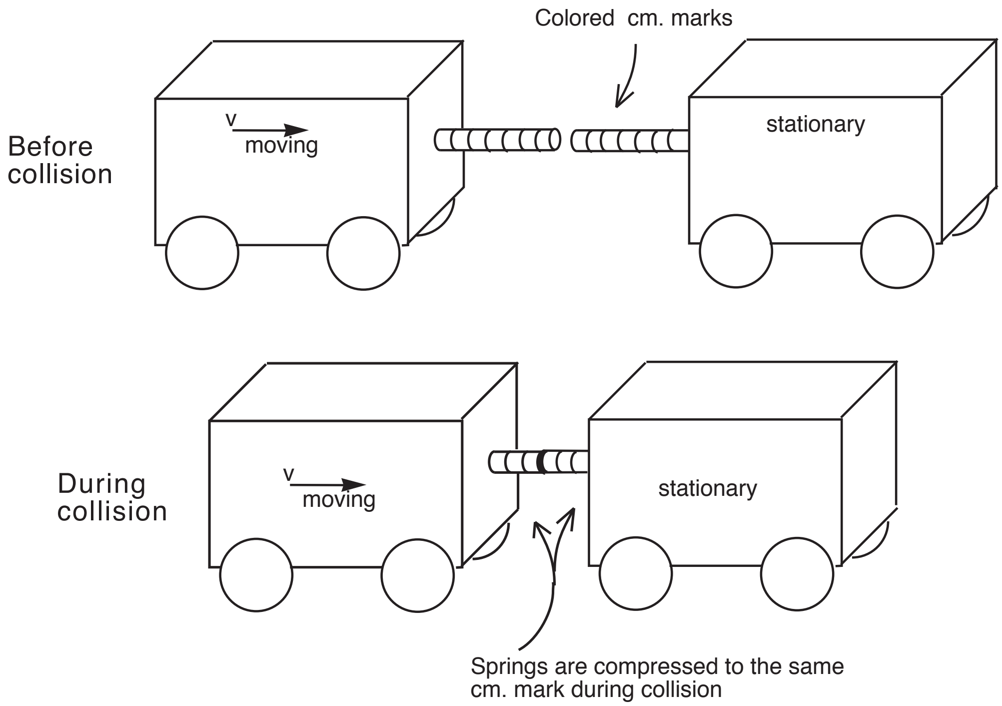


Figure 9.23

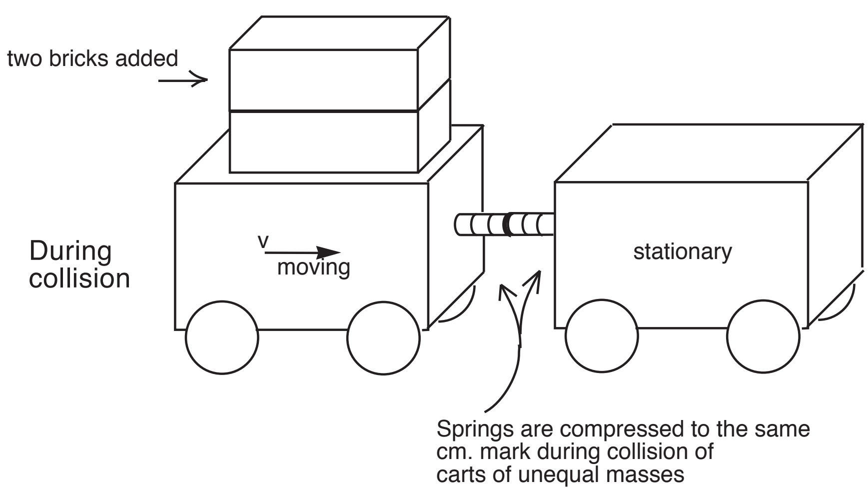


Figure 9.24

2.) During the impetus discussion the teacher should be watchful for student use of phrases such as "the force of inertia". Some will need repeated and careful reminders that inertia is an intrinsic property of mass and not a force.

VI. **MATERIALS FOR DUPLICATION**

A. Homework Problems

1.) Third Law in Dynamics - Day #1

2.) Third Law in Dynamics - Day #2

3.) Third Law in Dynamics - Day #3

4.) Third Law in Dynamics - Day #4

B. Activity Sheets

1.) Collision Analysis Activity

C. Quiz and Test Questions - Third Law in Dynamics

HOMEWORK THIRD LAW IN DYNAMICS - DAY #1

Name: ____________________

Period: _____ Date: __________

1.) Write an explanation, using the spring model, for how it is possible for one cart with a stiff spring to strike a stationary cart with a soft spring and yet have each of the forces exerted be equal and opposite during the collision.

2.) Write an explanation of how it is possible for a hard cart to collide with a cart with a weak balsa wood bumper (that crushes) and have the resulting forces be equal.

3.) (Challenge problem) When two carts of equal mass collide head-on at equal speeds it is obvious from symmetry considerations that the forces must be equal. Explain in terms of *relative motion considerations* why the forces must be equal and opposite for any collision of these two carts.

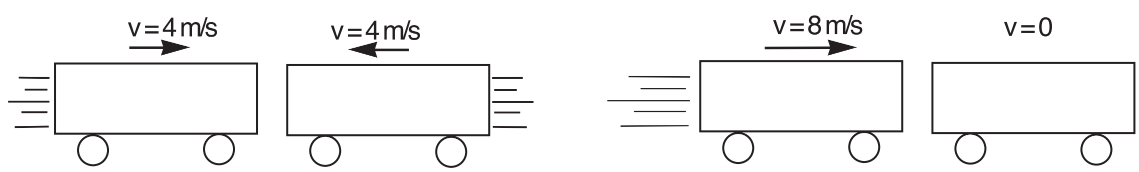


Figure 9.25

HOMEWORK - THIRD LAW IN DYNAMICS - DAY #2
(Collision Analysis Activity)

Name: ____________________

Period: _____Date: ___________

1.) In this head-on collision of equal masses neatly construct proper *force* and *velocity* vectors to approximate scale with clear labels. (Use a ruler.)

Frame 1

Frame 2

Frame 3

Frame 4

Frame 5

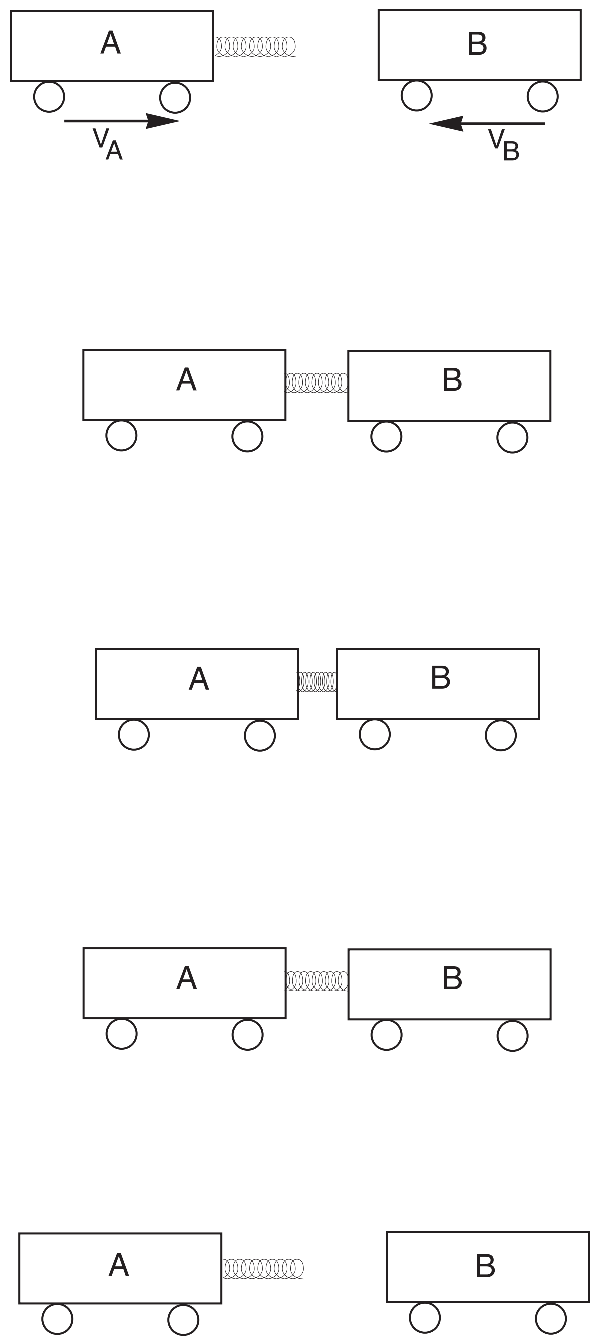


Figure 9.26

2.) In this head-on collision unequal masses are approaching at equal speeds. Properly construct and label all force and velocity vectors.

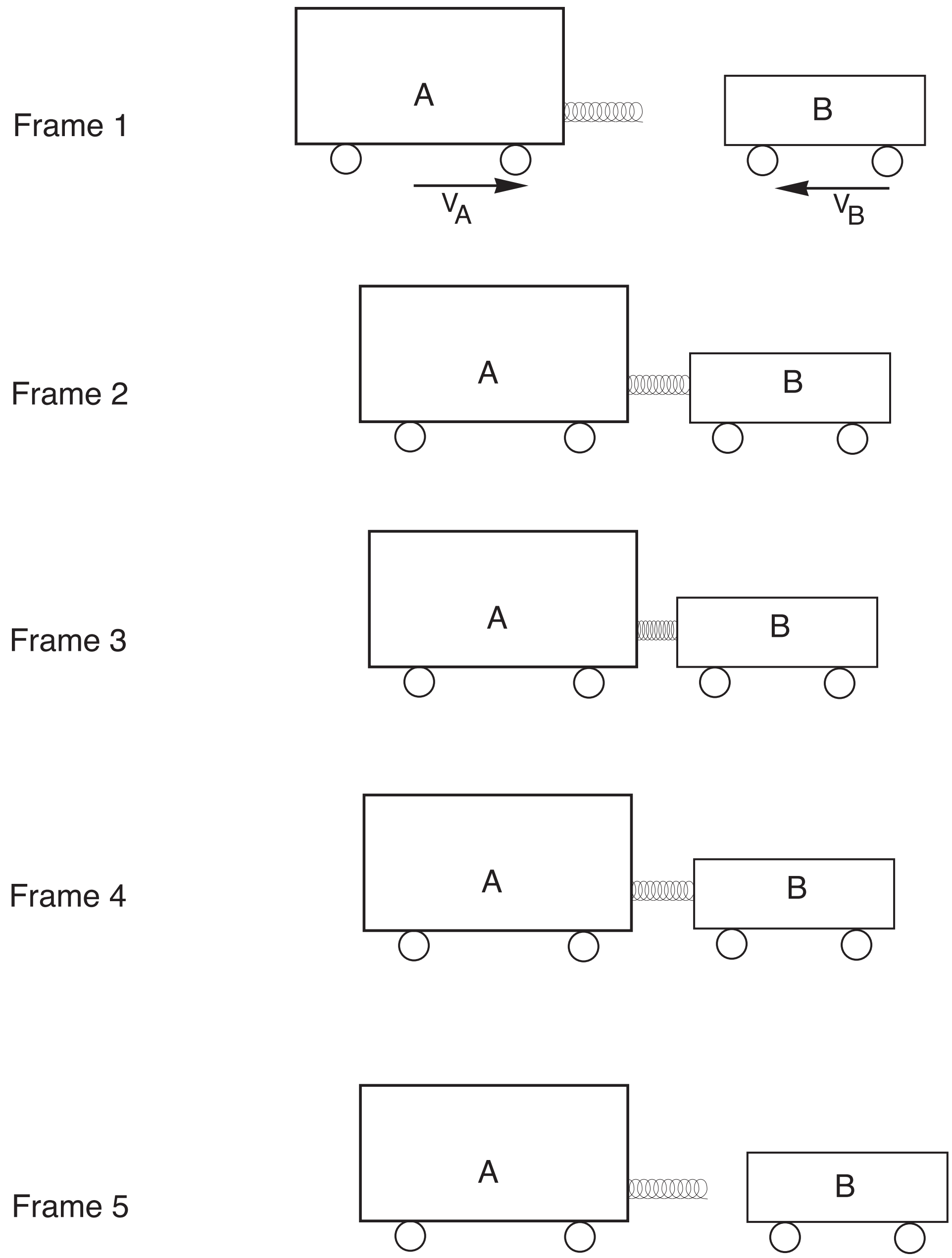


Figure 9.27

HOMEWORK - THIRD LAW IN DYNAMICS - DAY #3

Name: ____________________

Period: _____Date: __________

1.) A huge massive ball of soft clay flying through the air at 50 mph hits a cart and sticks to it. Explain using the spring model how the forces could be equal and opposite during this collision.

2.) A boxer in a brawl gets hit in the jaw with a fist, breaking his jaw. Explain how the forces could be equal and opposite during such an interaction.

3.) Write an explanation using the terms "spring" and "compression" to explain how the forces could be equal in the student collision demonstration where the massive student moving fast hits the small student who is stationary.

4.) Consider the collision of a 20 ton truck (at 40 mph) smashing into a small car. What would you expect to happen to the speed of the truck if the car stuck to the front of the truck (without dragging)? Estimate the final speed of the truck.

HOMEWORK - THIRD LAW IN DYNAMICS - DAY #4

Name: ____________________

Period: _____Date: __________

Consider the following situation with cart A coasting across a frictionless table and striking the less massive cart B which is at rest.

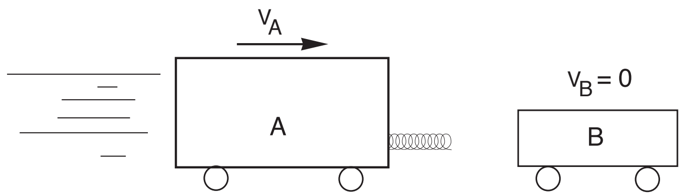


Figure 9.28

1.) Select the statement that most accurately describes the situation *before* the collision (in Figure 9.28).

a.) There is an external force acting *on* cart A, propelling it toward cart B.

b.) Cart A has an *internal* force propelling it toward cart B.

c.) There is both an internal force *in* cart A, and an external force *on* cart A propelling it toward cart B.

d.) There is neither an internal force *in* cart A nor an external force *on* cart A.

2.) What causes B to accelerate *during* the collision (shown above)?

a.) The force in A
b.) The force in B
c.) The force of A on B
d.) The force of momentum of B
e.) The force of inertia of A

Why are the others wrong?

3.) What causes B to keep moving *after* the collision (shown above)?

a.) The force in A
b.) The force in B
c.) The force given to B by A
d.) The force of A on B
e.) The force of momentum of B
f.) The force of inertia of B
g.) No cause is needed

Why are the others wrong?

4.) A 10 kg cart initially traveling 5m/sec collides with another 10 kg cart at rest on a frictionless surface. If the moving 10 kg cart slows to 1 m/sec what is the final speed of the stationary cart?

5.) Given a 20 kg cart moving 5 m/sec which collides with a 10 kg cart at rest, determine the final velocity of the 20 kg cart if the 10 kg cart speeds up to 4 m/sec.

6.) One 10 kg cart coasting towards the East at a speed of 2 m/s is hit from behind by another 10 kg cart going 6 m/s. Because there is a wad of bubble gum stuck to the back of the first cart the two carts stick together. How fast are the combined carts traveling?

7.) Fred throws a baseball to Sam.

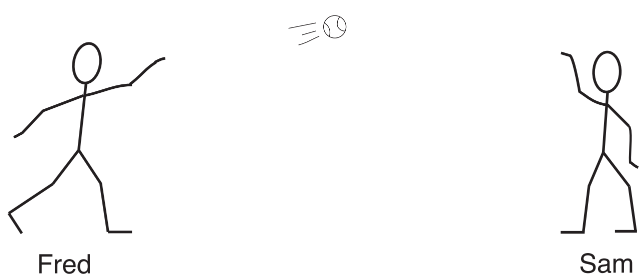


Figure 9.29

Draw a diagram (free body) showing all of the forces (neglect friction) acting on the ball when it is in the air half way from Fred to Sam. Label each force indicating what causes that force.

COLLISION ANALYSIS ACTIVITY SHEETS

Name: ____________________

Period: _____Date: __________

1.) Introduction

Each of the next three pages shows five "snapshots" of a collision between two frictionless carts. By labeling these diagrams we will be conducting a slow motion analysis of these collisions.

2.) Instructions

a.) For each cart diagram neatly construct (with a pencil and ruler) a horizontal force vector and label it as shown in the sample. Carefully adjust the length of each force vector so that it compares properly with the other force vectors.

b.) Below each cart's diagram construct an appropriate velocity vector. Carefully adjust the lengths of your velocity vectors so they correspond properly with the lengths of the other velocity vectors.

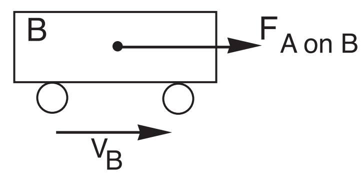


Figure 9.30

c.) Try the collisions shown on the next two pages with your carts and bricks to investigate the questions in this activity.

3.) Questions to help you check your work

a.) In each case where a cart feels a net force, does the cart speed up or slow down?
____

b.) How does the size of the force on cart A compare with the force on cart B in each "snapshot"?
____

c.) In which "snapshot" are the forces largest?
____

Experiment #1

In this collision of equal mass carts (one stationary) neatly construct proper force and velocity vectors, with labels, as indicated in the directions.

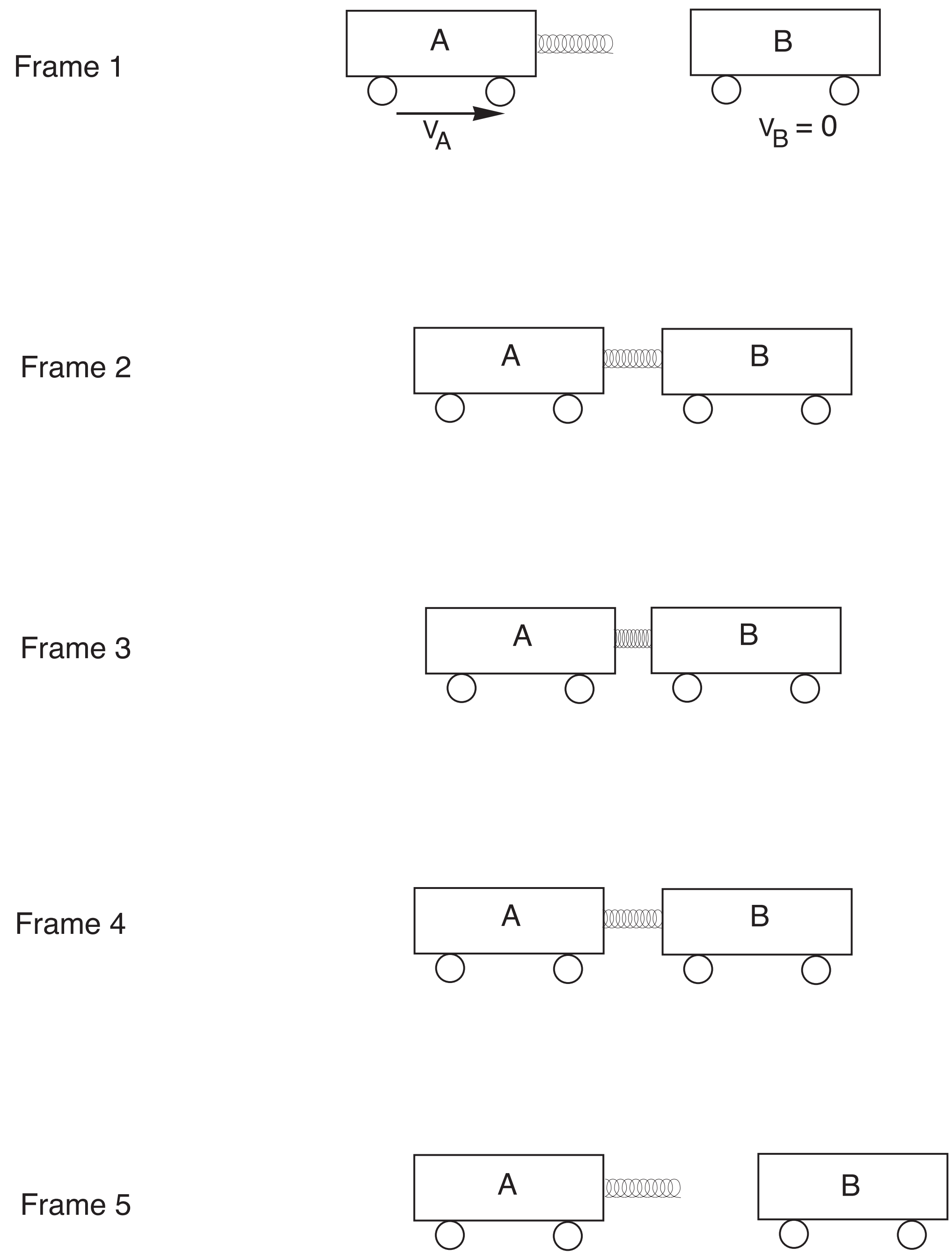


Figure 9.31

Experiment #2

For this collision of a large mass with a small stationary mass neatly construct and label appropriate force and velocity vectors for each mass.

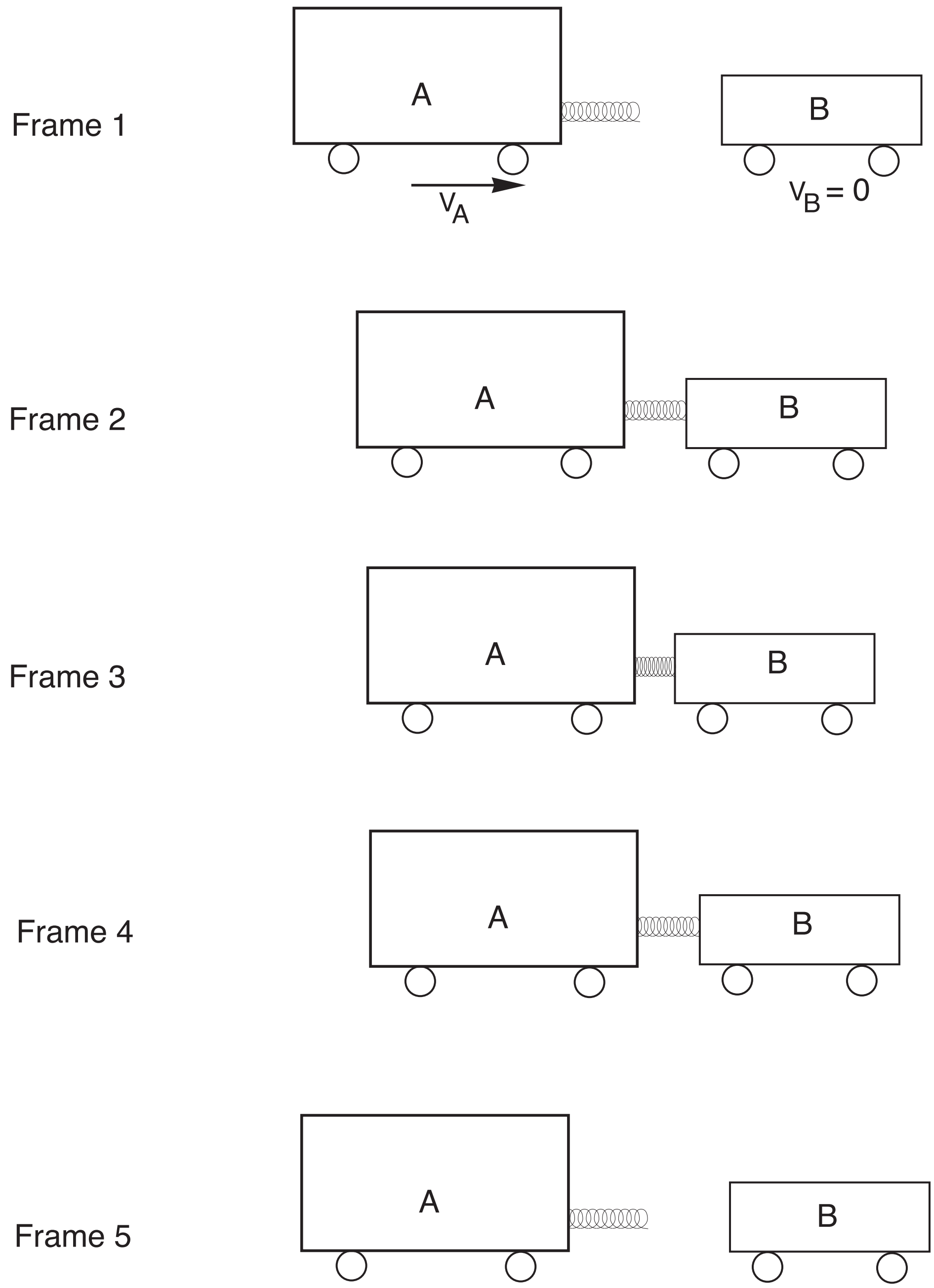


Figure 9.32

Experiment #3

In this collision a small moving mass strikes a large stationary mass. Neatly construct and label all the appropriate force and velocity vectors.

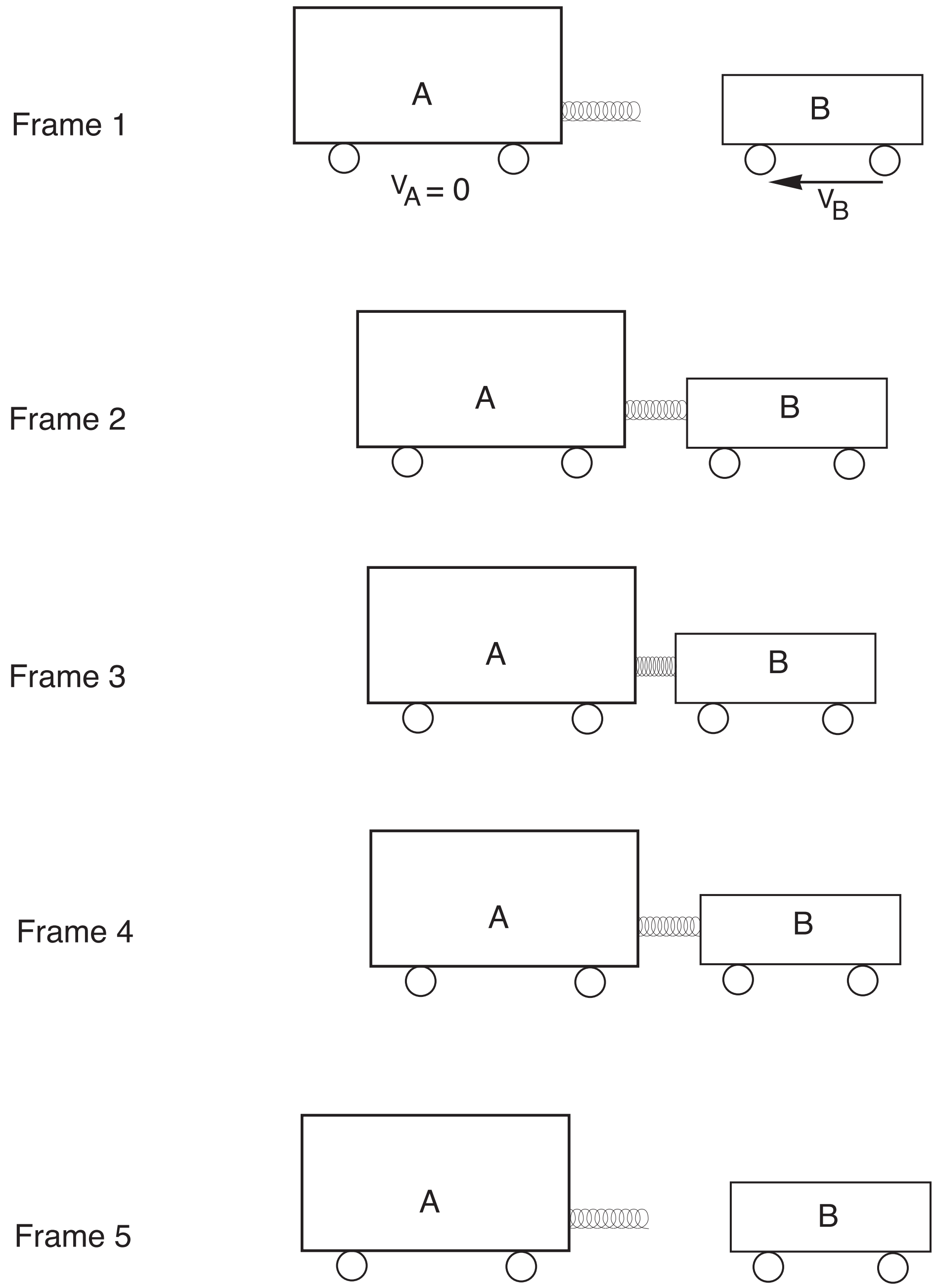


Figure 9.33

5.) <u>More experiments to try</u>

Can you predict the results before you try each collision?

a.)

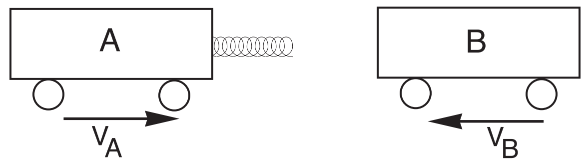


Figure 9.34

b.)

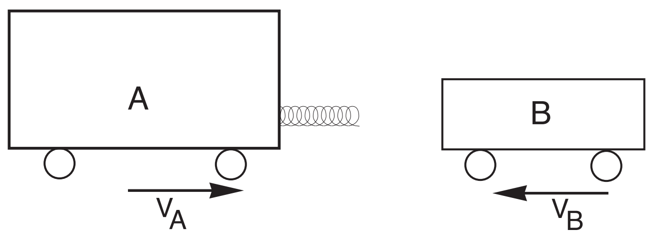


Figure 9.35

6.) <u>Review questions</u>

a.) What can you say about the general pattern of how the forces change during these collisions?

b.) What can you say is always true about the velocities in the middle "snapshot" where the spring is most compressed?

c.) When unequal masses collide, what can you say in general about how much the velocity of the small mass changes compared to how much the velocity of the big mass changes?

QUIZ AND TEST QUESTIONS - THIRD LAW IN DYNAMICS

1.) For each of the five "snapshots" of the collision below construct neat and clearly labeled *force* and *velocity vectors* .

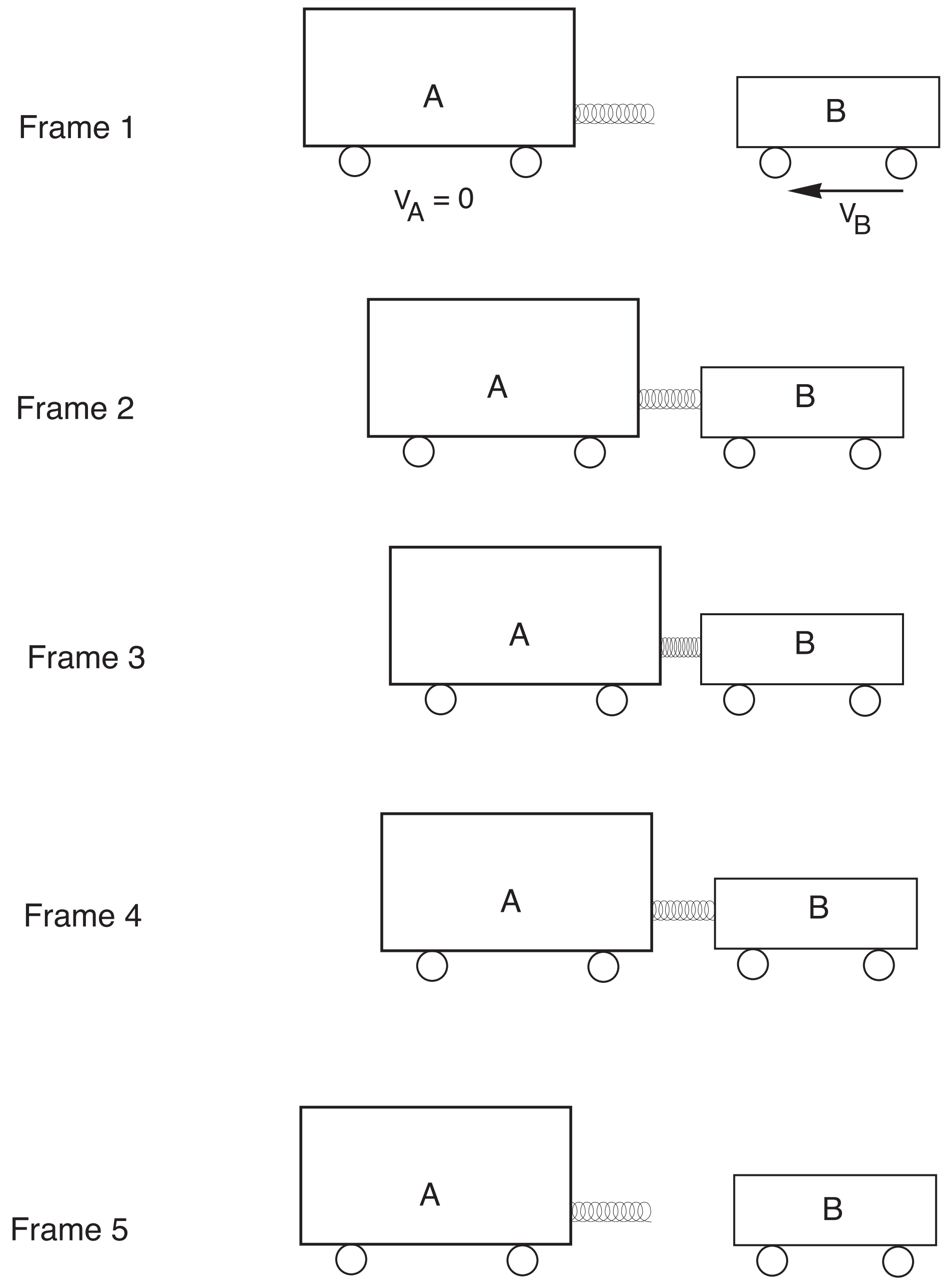


Figure 9.36

2.) If puck A collides with puck B on a frictionless air table what causes puck B to keep moving *after* the collision? Select the best answer.

a.) the force in A
b.) the force in B
c.) the force given to B by A
d.) the force of A on B
e.) the force of the inertia of B
f.) the force of the momentum of B
g.) no force is needed

3.) Explain why you would expect the maximum force during the collision on the left to be equal to the maximum force during the other collision shown of the right. Notice $m_1 = m_2$

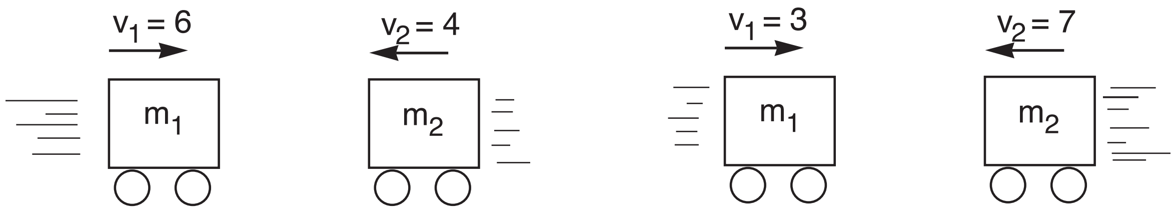


Figure 9.37

4.) Prove from fundamental considerations that the *change* in momentum of cart A is equal and opposite to the *change* in momentum of cart B during a collision. Start with a neat and clearly labeled diagram.

5.) Write an explanation, using the spring model, of how it is possible that the forces between a hard cart and a cart with a foam bumper pad could be equal during a collision.

6.) A 50 kg girl sits on a 30 kg cart which is at rest next to a 40 kg cart. She reaches over and shoves the 40 kg cart so it goes East at a speed of 12 m/sec.

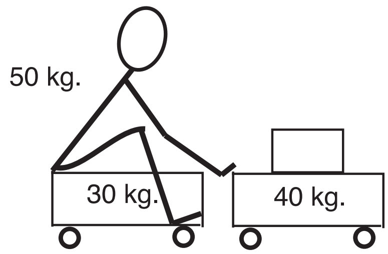


Figure 9.38

a.) How fast will the girl and the 30 kg cart go West? ____________________

b.) Which force was larger, the force of the girl pushing on the 40 kg cart or the force of the 40 kg cart pushing on the girl? ____________________

c.) Calculate the change in momentum (of the girl and the cart she is riding on).

____

7.) Kathy is driving her car with the accelerator on the floor so her car is moving forward with a large positive acceleration. Clearly label the separate diagram (free body) of Kathy showing all of the forces acting on her body and indicate both the type and source of each force.

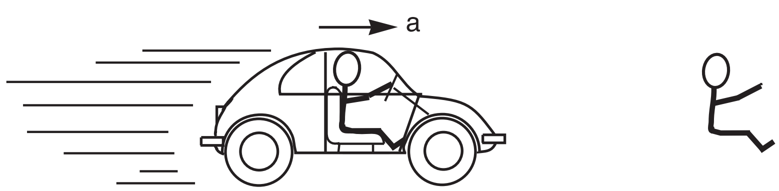


Figure 9.39

8.) Later when Kathy is going 100 mph, with her seat belt tight, she suddenly steps on the break very hard causing the car to have a large negative acceleration. Clearly label the free body diagram of only Kathy, indicating all the forces acting on her and show the type and cause of each force.

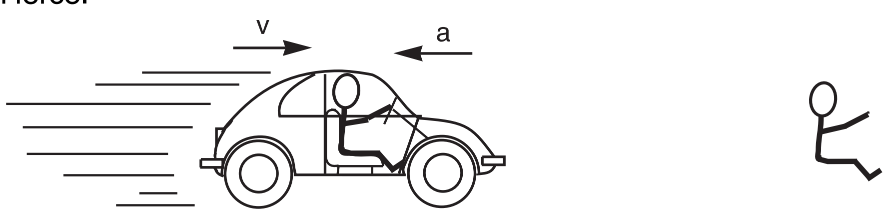


Figure 9.40

ANSWERS

TO

EXERCISES

ANSWERS TO EXERCISES

I. UNIT 1 - NORMAL FORCES

A. NORMAL FORCES - DAY #1 - HOMEWORK ANSWERS

1.) Students should convey the idea that the table compresses and bends slightly. The spring model of matter is useful in understanding why a table can push up on an object if all matter can be considered to be somewhat compressible.

2.) a.) One can think of the surface of the wall as slightly compressible and thus imagine how it exerts a force.
b.) Students might use the idea that the wall responds as if it were springy, compressing when a force is exerted on it.

3.) Students may have trouble using the spring model with very small forces such as the germ on the table. Reviewing the answer to #1 may help.

4.) a.) Answers will vary.
b.) Answers will vary.

Student responses to 4a and 4b may be helpful to the teacher in understanding students thinking and future lesson design.

5.) It is clear that springs push back when compressed by an object exerting a force. If all matter acts like springs, then any rigid object must push back when it is compressed.

B. NORMAL FORCES - DAY #2 - HOMEWORK ANSWERS

1.) Student answers will vary. Each spring will stretch or compress as much as necessary to exert the same force as the one attached to it. Weaker springs will compress more to exert the same force as will a stiffer spring that compresses a small amount.

2.) Rubber bands tend to "stretch out" or permanently deform so they do not respond to forces the same way each time a force is exerted. A rubber band is not useful in demonstrating compression, while a spring both compresses and elongates equally when the same force is exerted on it.

3.) a.) Force of A on B is less than the force of C on B. The force of C on B is the same as the force of B on C, which equals the weight of blocks A and B.
b.) The force of B on C.

4.) Student responses may be helpful to the teacher in understanding student thinking and future lesson design.

5.) a.) The forces are equal and opposite.
b.) The forces would be smaller but still equal and opposite.
c.) Block C does not exert a force on block A.
d.) Block B must be compressed, at least a small amount.

6.) Student answers will vary.

7.) Many students will refer to the class activity where two different rubber bands were placed on their fingers. They could not tell which finger felt the most force.

8.) Each of the three bricks must compress (get a little thinner) as each brick is acted on by larger normal forces on the top and the bottom.

9.) Many students will describe the "Baby Magnet Model" or make an analogy to weak and strong springs.

C. <u>NORMAL FORCES - ANSWERS TO QUIZ AND TEST QUESTIONS</u>

1.) The table will only push up on the book or paper clip with the same force as the book or paper clip exerts on the table. When the compression or bending of the table surface changes, the force exerted by the table automatically adjusts.

2.) The book exerts a normal force on the table and the table exerts an equal and opposite normal force on the book.

3.) Since it can be thought the table is composed of many small springs, the "springs" can act independently exerting forces as necessary.

4.) d.) Any two interacting objects exert equal and opposite forces on each other.

5.) d.) 300 N The rope and the person are a distraction

6.) a.) 25 N down
b.) 5 N up
c.) 5 N down
d.) We need to think of the ceiling as compressible like a table

II. UNIT 2 - RELATIVE MOTION

A. RELATIVE MOTION - DAY #1 - HOMEWORK ANSWERS

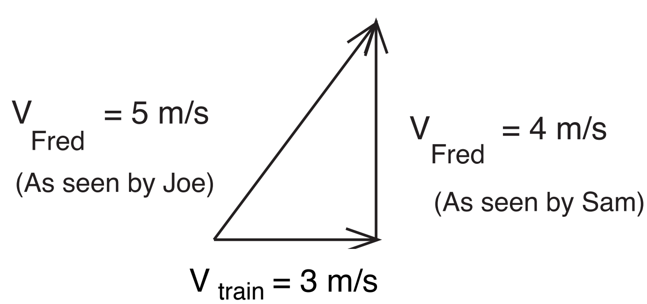
1.) a.) 50 m
b.) 50 m East
c.) 80 m East
d.) 5 m/s East
e.) 8 m/s East

2.) a.) 20 m
b.) 20 m West
c.) 10 m East
d.) 2 m/s West
e.) 1 m/s East
f.) It looks as if he is walking backwards

3.) a.) 30 m
b.) 0
c.) 3 m/s West
d.) 0
e.) Fred appears to be running in place.

4.) a.) 50 m West
b.) 20 m West
c.) 5 m/s West
d.) 3 m/s East
e.) 2 m/s
f.) 0

5.) a.)



b.) 4 m/s
c.) 25 m
d.) 4 m/s North
e.) 5 m/s Bearing 36.9°
f.) 3 m/s West

6.) All velocities and displacements should include directions.

7.)
a.) 2.0 m/s
b.) 23 m
c.) 2.0 m/s bearing 40°
d.) 4.5 m/s bearing 70°
e.) 3 m/s West

B. <u>RELATIVE MOTION - DAY #2 - HOMEWORK ANSWERS</u>

1.)
a.) 40 m
b.) 50 m South
c.) 8 m/s South
d.) 10 m/s South
e.) 2 m/s South

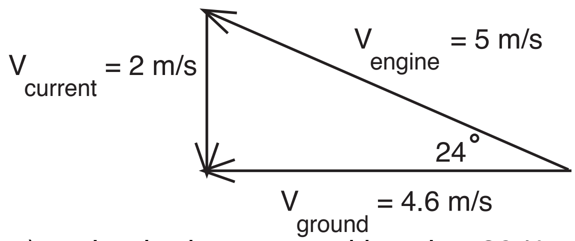
2.)
a.) 0
b.) 0
c.) 2 m/s South
d.) 2 m/s South

3.)
a.) 5 m/s North
b.) 3 m/s North
c.) 30 m North

4.)
a.) 2 m/s North
b.) 2 m/s South
c.) 0

5.)
a.) 50 m
b.) 5 m/s West
c.) 5.4 m/s bearing 248°
d.) 20 m
e.) 20 m

6.)



a.) point the boat toward bearing 294°
b.) 4.6 m/s West
c.) (50 m / 4.6 m/s) = 10.9 s
d.) 5.0 m/s
e.) 5.0 m/s bearing 294°
f.) The boat should point straight toward the inner tube. Note the traveling swimming pool idea is very helpful here.

C. <u>RELATIVE MOTION - DAY #3 - HOMEWORK ANSWERS</u>

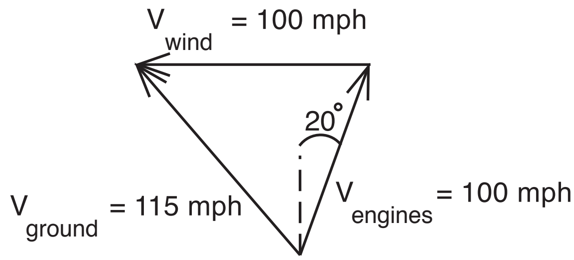
1.) a.) 200 mph East
b.) 240 mph
c.) 200 mph East
d.) 600 miles East

2.) a.) 200 mph
b.) 160 mph West
c.) 200 mph West
d.) 800 miles
e.) 0

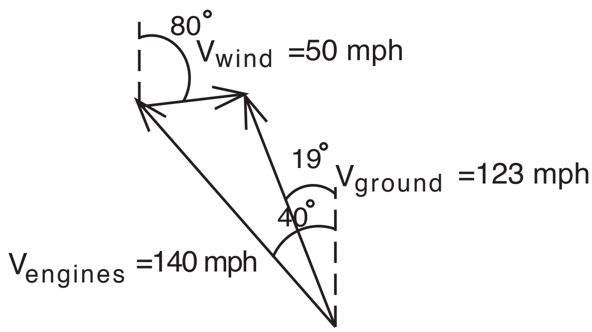
3.) a.) 200 mph North
b.) 204 mph
c.) 40 mph East
d.) 714 miles bearing 11°

4.) a.) 100 mph East
b.) 50 mph West
c.) 100 mph
d.) 125 miles West
e.) The plane is pointed East but moving toward the West over the ground. It does not fall down as long as it has enough fuel.

5.) a.) 0
b.) No flag motion
c.) Thick coat, no wind

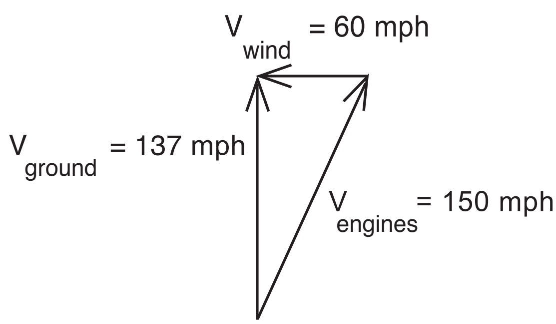


6.)
a.) 100 mph bearing 20°
b.) 115 mph bearing 325°
c.) 100 mph
d.) 287 miles bearing 325°
e.) Pilot should point straight toward the balloon.



7.)
a.) 140 mph
b.) 140 mph bearing 140°
c.) 123 mph
d.) 221 miles bearing 341°

8.) a.) Bearing 23.6°
b.) 137 mph due North
c.) 150 mph bearing 203.6°
d.) 343 miles due North
e.) When one is not given the bearing of the plane, it is necessary to work backwards in order to find the unknown angle for the plane's bearing.



D. **RELATIVE MOTION - VECTOR RIVER ACTIVITY ANSWERS**

II. A. Full Speed Down Stream

1.) 0.3 m/s South
0.3 m/s South
0.7 m/s South

2.) 0
0.4 m/s South
0.3 m/s North

3.) 0.4 m/s North
0.4 m/s North
0.7 m/s North

B. Full Speed Up Stream

1.) 0.3 m/s South
0.3 m/s South
0.1 m/s North
$V_{engine} > V_{current}$
$V_{engine} < V_{current}$

2.) 0
0.4 m/s North
0.3 m/s North

3.) 0.4 m/s South
0.4 m/s South
0.1 m/s South
V_{engine} = 0.3 m/s North

C. Full Speed Across the River

1.) 0.3 m/s
0.3 m/s
0.5 m/s

2.) 0
0.4 m/s
0.3 m/s

3.) 0.4 m/s
0.4 m/s
0.5 m/s

III. A. The swimmer's effort arrow should be in a generally northeast direction while the path relative to the shore goes due east.

B. The swimmer's effort this time points due east while the path relative to the shore is in a generally southeast direction.

E. **RELATIVE MOTION – QUIZ AND TEST ANSWERS**

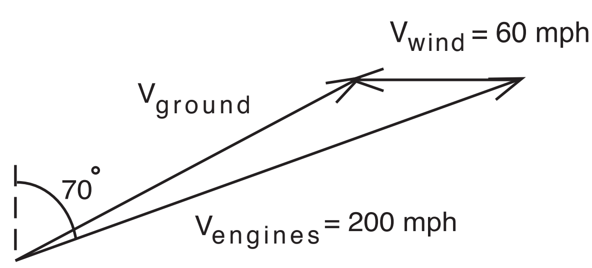
1.) a.) 20 meters
b.) 35 meters East
c.) 4 meters/sec East
d.) 7 meters/sec East
e.) 3 meters/sec East

2.) a.) 5 meters/sec East
b.) 0
c.) 2 meters/sec East
d.) 3 meters/sec
e.) 3 meters/sec
f.) 0
g.) directly south

3.) a.) 100 mph East
b.) 20 mph West
c.) 100 mph
d.) 70 Miles West
e.) 200 Miles East
f.) 100 mph
g.) Plane does not reach the airport

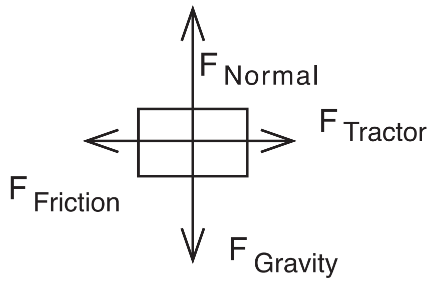
4.) a.) 145 mph bearing 61.9°
b.) 200 mph bearing 70°
c.) 363 Miles
d.) 61.9°

5.) The same effort is required swimming either up stream or down stream. Think of the swimming pool and use the water as the frame of reference.



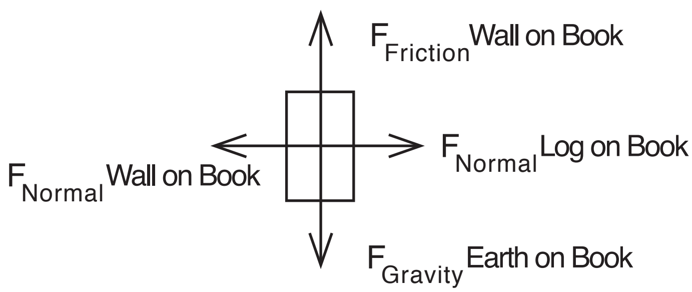
III. UNIT 3 - SURFACE FRICTION FORCES

A. SURFACE FRICTION - PRE - QUIZ ANSWERS



B. SURFACE FRICTION FORCES - HOMEWORK ANSWERS

1.)



2.) a.) A picture should be drawn showing bumps on the book locked together with bumps on the wall.

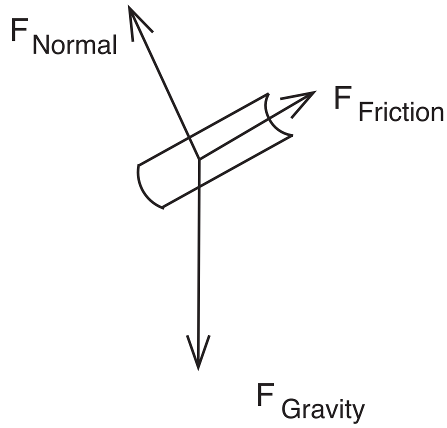
b.) See the diagram for Question #1 above.

3.) a.) 5N

b.) 5N

4.) Air resistance and/or water resistance depend on the shape of the object, the density of the fluid, and the relative velocity between the object and the fluid. Resistance forces should be shown on the front and the sides of the block.

5.) a & b)



6.) Friction is a force that acts to oppose the relative motion between the two surfaces. The force acts parallel to the surfaces. This force acts parallel to the surfaces.

7.) Answers will vary

C. SURFACE FRICTION FORCES - QUIZ AND TEST ANSWERS

1.) a.) Down

b.) Up

c.) Toward Left

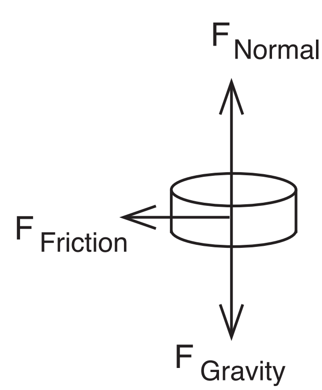
d.) Toward Right

e.) Down

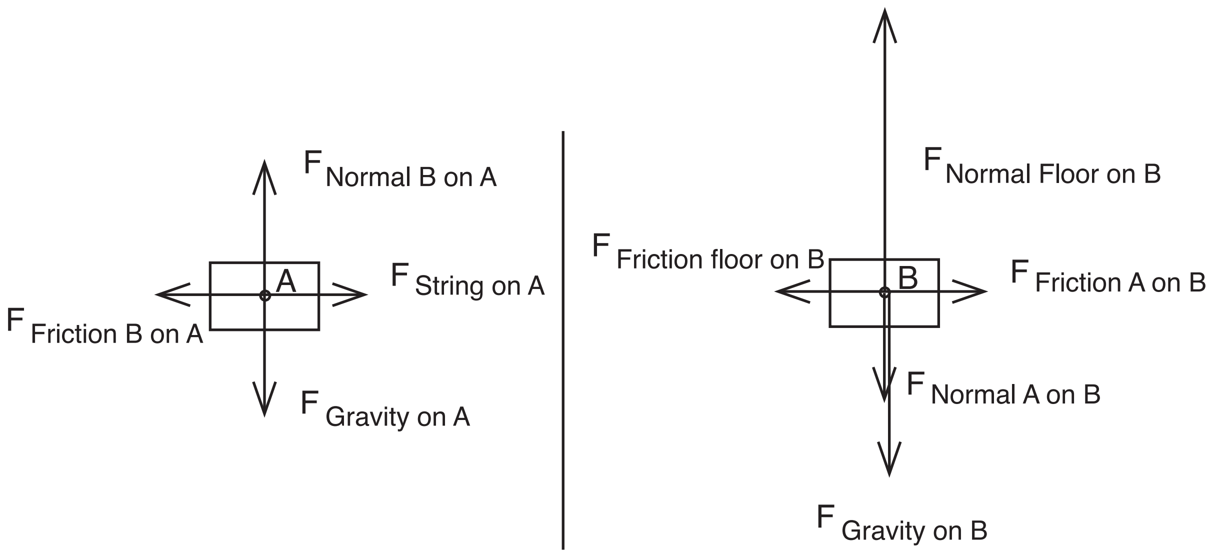
f.) None

2.) A=B=E and C=D

3.)



4.) a.)



b.) $F_{\text{String on A}} = F_{\text{Friction B on A}}$
$= F_{\text{Friction A on B}} = F_{\text{Friction Floor on B}}$

$F_{\text{Normal B on A}} = F_{\text{Normal A on B}} = F_{\text{Gravity on A}}$

$F_{\text{Normal Floor on B}} = F_{\text{Normal A on B}} + F_{\text{Gravity on B}}$

c.) The diagrams for part c are the same as those for part a shown above.

5.) a.) The table exerts upward force on book equal in magnitude to the gravitational force downward on the book.

b.) The scale exerts a force to the left on the book equal in magnitude to the force of friction the table exerts on the book to the right.

c.) See Figure 3.21; reverse x-axis vectors.

d.) $F_{\text{Normal, Table on Book}} = F_{\text{Gravitational, on Book}}$

$F_{\text{Tension, Scale on Book}} = F_{\text{Friction, Table on Book}}$

6.) a.) F

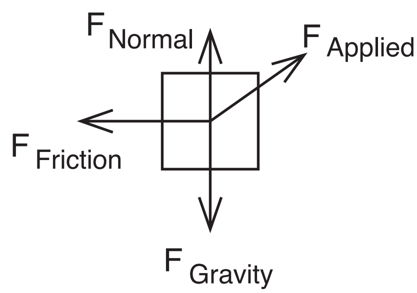
b.) B

7.) a.) B

b.) F

8.) See the answer to Surface Friction Homework #1.

9.) a.)



b.) $F_{Applied\ x} - F_{Friction} = 0$

c.) $F_{Normal} + F_{Applied\ y} - F_{Gravity} = 0$

10.) a.) is the correct choice

IV. UNIT 4 – TENSION FORCES

A. TENSION FORCES - DAY #1 - HOMEWORK ANSWERS

1.) The spring scale would behave the same when turned around because the spring inside is symmetrical.

2.) Holding the scale upside down, one is weighing the body of the scale in addition to the attached load.

3.) The rubber rope elongates much more than the strong rope, but it automatically adjusts so that the cart feels equal forces from both ropes. Thus the cars must also feel equal forces.

4.) a.) 150 N

b.) 450 N

5.) a.) 30 N to the left

b.) 30 N to the right

c.) 30 N

6.) a.) 100 N

b.) 100 N

c.) 250 N

d.) 150 N

e.) 150 N

7.) a.) 20 N to the left

b.) 60 N

c.) 80 N

B. **TENSION FORCES - DAY #2 - HOMEWORK ANSWERS**

1.) a.) 20 N Right

b.) 20 N

c.) 20 N

d.) The pulley is frictionless.

2.) Answers will vary.

3.) If the tension in the two ropes were not equal, then the cart in the middle would move. The rubber rope stretches much more than the strong rope in order to exert an equal force.

4.) a.) 410 N

b.) The pulley is frictionless and the weight of the swing seat is very small.

5.) 820 N

6.) Put a spring scale between the end of the rope and the object pulling on that end of the rope.

7.) a.) 60 N, 30 N, 30 N b.) 60 N

8.) Attach a spring scale to either end or cut the rope and insert the scale.

9.) It means that each person is exerting a force equal in magnitude to the reading on the spring scale.

10.) The force exerted by the wall is a vector pointing to the left and the force exerted by the mass is a vector pointing down. The tension in the rope is a scalar equal in size to each of the two vectors.

C. **TENSION FORCES - QUIZ AND TEST ANSWERS**

1.) a.) 900 N; The rope attached to the scale must support the entire weight of the worker.

b.) 900 N; Same explanation as in part a.

c.) 900 N; The rope attached to each end of the spring scale must have a tension of 900 N.

d.) 900 N; The tension is 900 N throughout the system.

2.) a.) Picture with one side of Superman attached to a tree and two horses together pulling on his other arm.

b.) The tension in the system will equal twice the force exerted by one horse alone.

3.) Both scales will be the same because the slinky will elongate more in order to balance the force of the stiff spring.

4.) 720 N, 360 N

5.) a.) 600 N

b.) 400 N

c.) 200 N

d.) Left

V. UNIT 5 – GRAVITATIONAL FORCE I

A. GRAVITATIONAL FORCE I - DAY #1 - HOMEWORK ANSWERS

1.) a.) The scale reading would not change. (If the scale were very accurate, there would be a slightly decreased reading due to the greater buoyancy of the denser air.)

b.) No change

c.) No change

2.) a.) No change

b.) Yes. Especially near the equator, scale readings would show a small increase (less than 1%). There would be a smaller effect as one moves toward the poles.

3.) One would probably aim high expecting it to curve down and would therefore hit the "ceiling".

4.) Answers will vary, but it is important for students to find that there are many people (even adults) who hold views about gravity that physicists consider incorrect.

B. GRAVITATIONAL FORCE I - DAY #2 - HOMEWORK ANSWERS

1.) a.) Yes

b.) Yes

c.) Perhaps show my friend the video of the Cavendish experiment as evidence that small masses can exert a gravitational force.

2.) One would expect the gravitational force of the plane to pull up slightly on a person, but it would not be enough to noticeably reduce the scale reading.

3.) Small decrease, but not enough to notice on a regular bathroom scale. There are fewer masslets directly below pulling down on the person.

4.) Tell your friend about the Cavendish experiment.

5.) a.) Magnetism does not seem to work on things like wood and plastic, but a gravitational force attracts all kinds of mass.

b.) A gravitational force only attracts, but magnets can attract or repel.

6.) Nothing seems to shield out the gravitational force.

7.) Nothing can shield out a gravitational force.

8.) The forces are equal and opposite. One would expect them to move toward each other, with the smaller one moving faster.

9.) Answers will vary.

10.) Answers will vary - (binary stars are a good example).

11.) Anything that does not have mass is not attracted.

12.) a.) Yes, the Earth is attracted to the falling tennis ball.

b.) One would not expect the Earth to move a distance that could be detected by any instrument. Objects falling on the other side of the Earth simultaneously could easily produce equal and opposite forces.

C. **GRAVITATIONAL FORCE I - QUIZ AND TEST ANSWERS**

1.) a.) Place an object on a bathroom scale in a closed container, pump in air, and watch the scale reading.

b.) No change is expected because the gravitational force stays the same and the change in air pressure will have only a tiny effect.

2.) As the Earth spins faster, objects tend to lift off the surface (go straight). The direction of this effect is opposite to the direction of the gravitational force.

3.) The Cavendish Experiment.

4.) a.) Stay the same.

b.) If a student answers "increase" in part a, the student should indicate a very small increase due to the loss of the buoyant force of the air.

c.) The gravitational force is not caused by air pressure.

5.) No, although the big object would pull me slightly to the side, I would expect the Earth to pull down on me the same amount.

6.) a.) Stay the same. The Earth's spin has nothing to do with the gravitational force. At the equator an average person's scale reading is decreased by about half a pound due to the centrifugal force.

b.) The bathroom scale reading would decrease because your body would tend to lift off the scale as it tries to go straight. The bathroom scale reading would be decreased by more than 5%.

7.) The person would feel almost equally attracted to both "Earths" and would, thus, feel virtually weightless and could float around.

VII. **UNIT 6 – GRAVITATIONAL FORCE II**

A. **GRAVITATIONAL FORCE II - DAY #1 - HOMEWORK ANSWERS**

1.) a.) =; 12 force lines pulling in both directions

b.) >; 12 lines > 10 lines

c.) <; 10 lines < 12 lines and E-F are nearer

d.) <; 12 lines < 20 lines

2.) We have explained gravity by saying that every "masslet" pulls on every other "masslet", therefore, the feather must pull on the planet.

3.) (4 x 30) > (5 x 20) so, b is the answer. The distances from the center of the truck to the center of the building are assumed to be the same in both cases.

4.) See problem 2 answer above.

5.) a.) Answers will vary.

b.) Answers will vary.

6.) Yes, the Earth should move up, but one would expect the distance to be too small to measure with any available instrument.

7.) Answers will vary.

8.) a.) No change expected.

b.) There is no material that will shield out gravity.

B. GRAVITATIONAL FORCE II - DAY #2 - HOMEWORK ANSWERS

1.) $F_2/F_1 = (3 \times 7)/(2 \times 8) = 21/16$

2.) a.) The force would be 3 times larger.

b.) Increased tidal effects.

3.) a.) Decrease

b.) $F_2/F_1 = 3/4$

4.) a.) $F_2/F_1 = 1/9$

b.) $F_2/F_1 = 9/1$

c.) $F_2/F_1 = 1/1$

5.) There should be a force line from each masslet in one object to each masslet in the other objects.

6.) a.) No change.

b.) One half the force.

c.) Twice the force.

7.) The student has not considered the fact that the distance between the book and the center of the Earth is also changing as one climbs the mountain. Thus, the experiment can have confusing results as two variables are changing at the same time.

C. GRAVITATIONAL FORCE II - QUIZ AND TEST ANSWERS

1.) The forces are equal.

2.) a.) No change - 1/1

b.) No change - 1/1

3.) The force is smaller because the candy bar now has fewer masslets for the dump truck to attract with its force of gravity.

4.) a.) F = 1 N

b.) Yes, the Earth still feels a force of gravity from the feather.

5.) a.) $F_2/F_1 = 10/1$

b.) $F_2/F_1 = 1/1$

c.) $F_2/F_1 = 4/1$

VI. UNIT 7 - INERTIA

A. INERTIA - PRE - QUIZ ANSWERS

1.) b
2.) a
3.) b
4.) b

B. INERTIA - DAY #1 - HOMEWORK ANSWERS

1.) Student answers will vary. Some possibilities might include;
- more massive objects resist a change in motion more than less massive objects.
- the more massive skateboarder is attracted by a larger gravitational force.
- the more massive skateboarder may experience more frictional forces (from the floor and air) than the less massive person.

2.) Student answers will vary.

3.) Student answers will vary.

4.) a.) You would eventually slow to a stop due to opposing frictional forces. If there were no friction the bicycle would continue at a steady speed.

b.) Student answers will vary.

C. INERTIA - DAY #2 - HOMEWORK ANSWERS

1.) I.) b

II.) d

III.) a.) Sarah will keep going straight at a steady speed.

b.) Friction, the length of the room or floor.

2.) a.) Approximately ten meters. The tendency of the object to resist change in motion is the same for starting and stopping. However, friction influences stopping time and distance. If there were no friction, starting and stopping time and distance would be the same given the same force is exerted for the same amount of time.

b.) Approximately the same time (see notes from #4a).

3.) Harry will stop first because he has less mass and his motion will be easier to change.

D. INERTIA - SKATEBOARD LAB - ACTIVITY #1 ANSWERS

Answers will vary with each student group.

Procedure I

5.) a.) Time/distance chart

b.) Accelerated motion. When the skateboard was pulled with a constant force it accelerated the entire journey.

Procedure II

1.) Prediction - The larger the mass the lower the rate of acceleration.

2.) Data chart.

3.) Motion was still accelerated with the larger mass but rate of acceleration was lower.

Procedure III

1.) Predictions will vary.

2.) Explanations of predictions will vary.

3.) Students compare prediction with results.

4.) Friction is an opposing force which tends to decelerate the coasting skateboarder.

5.) Friction is not large enough to immediately overcome the "keep going property" of the skateboarder bringing him/her to an immediate stop.

6.) Less friction would allow the skateboarder to travel further along the path.

7.) No friction would result in a continuation of the motion of the skateboarder.

To Sum Up

1.) Accelerated motion.

2.) The greater the mass, the more the object resists change in motion.

Challenge Questions

1.) Old skateboards sometimes stop more quickly because the greater weight causes a big increase in the friction force.

2.) A very low friction skateboard would go further with greater mass to "keep it going".

3.) Measure the deceleration and mass then use $F = ma$.

E. **INERTIA - ANSWERS TO QUIZ AND TEST QUESTIONS**

1.) More force. She had to decelerate more mass in the same amount of time requiring more force.

2.) It will take the same amount of force since he is decelerating the same amount of mass in the same amount of time. (The hold back property equals the keep going property.)

3.) The force exerted by A on B is the same as the force exerted by B on A. The inertia of both pucks were the same. Since the first was traveling at 30 km/sec and came to rest while the second puck started at rest and traveled off at 30 km/sec, the force slowing A down must have been equal in size to the force speeding B up.

4.) The coin has mass, therefore inertia and a property to resist change in motion. The more massive the coin, the more resistance to change of motion.

5.) The inertia of the ball does not change, therefore the amount of force required to change the motion of the ball is the same. Since the height of the ball is a function of the force required to stop it and the force required to start it is the same as it is to stop it, it will rise to the same height as it started from at starting point A.

6.) The tension in A must be greater than the tension in B or the car between A and B would not accelerate.

7.) If we consider that there are no frictional forces on either planet the results would be the same since gravity does not effect the amount of mass (inertia) of the skateboarder.

VIII. UNIT 8 - INERTIA AND GRAVITATIONAL FORCE

A. INERTIA AND GRAVITATIONAL FORCE – PRE-QUIZ - ACTIVITY ANSWERS

1.) Set up.

2.) Both carts will be pushed to the same speed. They will also have the same backward force exerted on each. The mass of each cart is different.

3.) Student prediction and explanation.

4.) Students test prediction.

5.) Student explanation using assigned vocabulary. Students should discover that the more massive cart did not stop as quickly as did the less massive cart. The more massive cart has more "keep going property".

6.) Students might try trading the load to the other cart.

7.) Changing the hanging masses (opposing force) can make the carts stop together.

8.) a.) Student prediction.

b.) Students test prediction. (Stopping rate and starting rate should be about the same using the original hanging masses.)

B. INERTIA AND GRAVITATIONAL FORCE - DAY #1 - HOMEWORK ANSWERS

1.) d, Weight would be less (essentially zero). All others experience no change.

2.) It takes the same amount of fuel to start as to stop a rocket ship.

3.) Inertia is the property of an object that resists change in motion. The more massive the object, the more inertia it has.

4.) Gravity is the attraction of an object to the Earth or other celestial body. Inertia is not effected by gravity, it is only a function of mass. Inertia is an intrinsic property of an object and it is not effected by external forces.

5.) b, The tug is exerting a constant force which will accelerate the larger ship, but because the larger ship is so massive the rate of acceleration will be very low.

6.) Yes. Gravity is not necessary for inertia to exist.

7.) No. Friction is a force. Inertia is not a force, rather an inherent property of objects that resists a change in motion.

8.) No. The contact and rubbing of one surface against another causes surface friction.

9.) a.) #3
b.) #2

A greater force will be required to stop the more massive object therefore the door will have to exert a greater force to stop the more massive ball so the door will dent more.

10.) If they have the same volume, find the mass or weight of each. The one with the greater mass or weight will have the greater density.
On the Earth the meteorites could be weighed and in space they could be tested to see which one most resisted a change in motion (acceleration). Perhaps one could creatively set up the Cavendish apparatus in space.

C. INERTIA AND GRAVITATIONAL FORCE - DAY #2 - HOMEWORK ANSWERS

1.) a.) The rock

b.) The figure showing both reaching the surface at the same time.

c.) No.

d.) Same results. The only difference would be that their rate of acceleration on the Earth would be greater.

2.) a.) Mass remains the same. Weight reduces.

b.) Mass remains the same. Weight increases.

c.) Mass remains the same. Weight reduces to essentially zero.

3.) A large object has a greater force exerted on it from the Earth's gravitational field, however, it also has proportionally more inertia so it resists a change in motion (acceleration).

4.) They will each reach the same height. The larger has more inertia but it also experiences a greater gravitational attraction.

5.) All objects fall at the same rate. Mass does not effect falling rate. The length of the pendulum changes the speed of the clock.

6.) a.) Both will hit the surface at the same time.

b.) The one dropped on the high mass planet.

c.) The high mass object should cause its planet to move up a slightly greater distance to meet it.

7.) Both objects would strike the Moon's surface at the same time. On the Earth the paper would fall slower due to air resistance.

D. **SUPPLEMENTAL HOMEWORK OR EXAM QUESTIONS CONCERNING GRAVITATIONAL FORCE, FRICTION FORCE, AND INERTIA ANSWERS**

1.) Static friction force is greatest just before an object starts to slide.

2.) Since the slope is very gradual, we would assume inertia is the most important factor.

3.) With no acceleration in this situation, the gravitational force is the major influence.

4.) Both inertia and the gravitational force are of primary influence.

5.) The inertia of the cart would cause a very large tension force in the rope during the very rapid deceleration.

6.) Since the slope is small and the block is rough, the friction force has the greatest influence.

7.) Although there is a small acceleration in this situation, the effect of the maximum static friction (starting friction) is more important that inertia.

8.) Both the inertia of the added mass and the gravitational force acting on the added mass must be considered.

9.) Gravitational force is the big issue here.

10.) With a frictionless cart the same force is required.

E. **INERTIA AND GRAVITATIONAL FORCE - ANSWERS TO QUIZ AND TEST QUESTIONS**

1.) No. The man will have a lower velocity. Slope of the boy's graph will be steeper.

2.) The Earth exerts a greater force on the quarter, but it is harder to accelerate its greater mass. These factors compensate exactly.

3.) The Earth does exert a greater force on the more massive ball, but the more massive ball also has more inertia causing it to resist falling. Therefore, both balls will fall at the same rate of acceleration.

4.) A gravitational force acts downward on each ball. The force of air friction is opposite to the velocity and absent in the zero velocity diagram (at the top).

5.) Ignoring air friction, both balls fall at the same rate of acceleration and will strike the ground at the same time. Since both have the same initial horizontal velocity they will have identical paths.

6.) a.) It has a steady speed.

b.) There is no external or internal force.

7.) a.) Requires a masslet diagram. Answers will vary. The Earth could have 5 masslets, A could have 4 masslets, and B could have 1 masslet.

b.) $F_{on\ A} / F_{on\ B} = 4/1$

c.) A

d.) A

e.) A is 4 times as hard to accelerate

f.) The accelerations will be equal

g.) They will hit at the same time. A feels 4 times as much force, but is 4 times harder to accelerate.

IX. UNIT 9 - THIRD LAW IN DYNAMICS

A. THIRD LAW IN DYNAMICS - DAY #1 - HOMEWORK ANSWERS

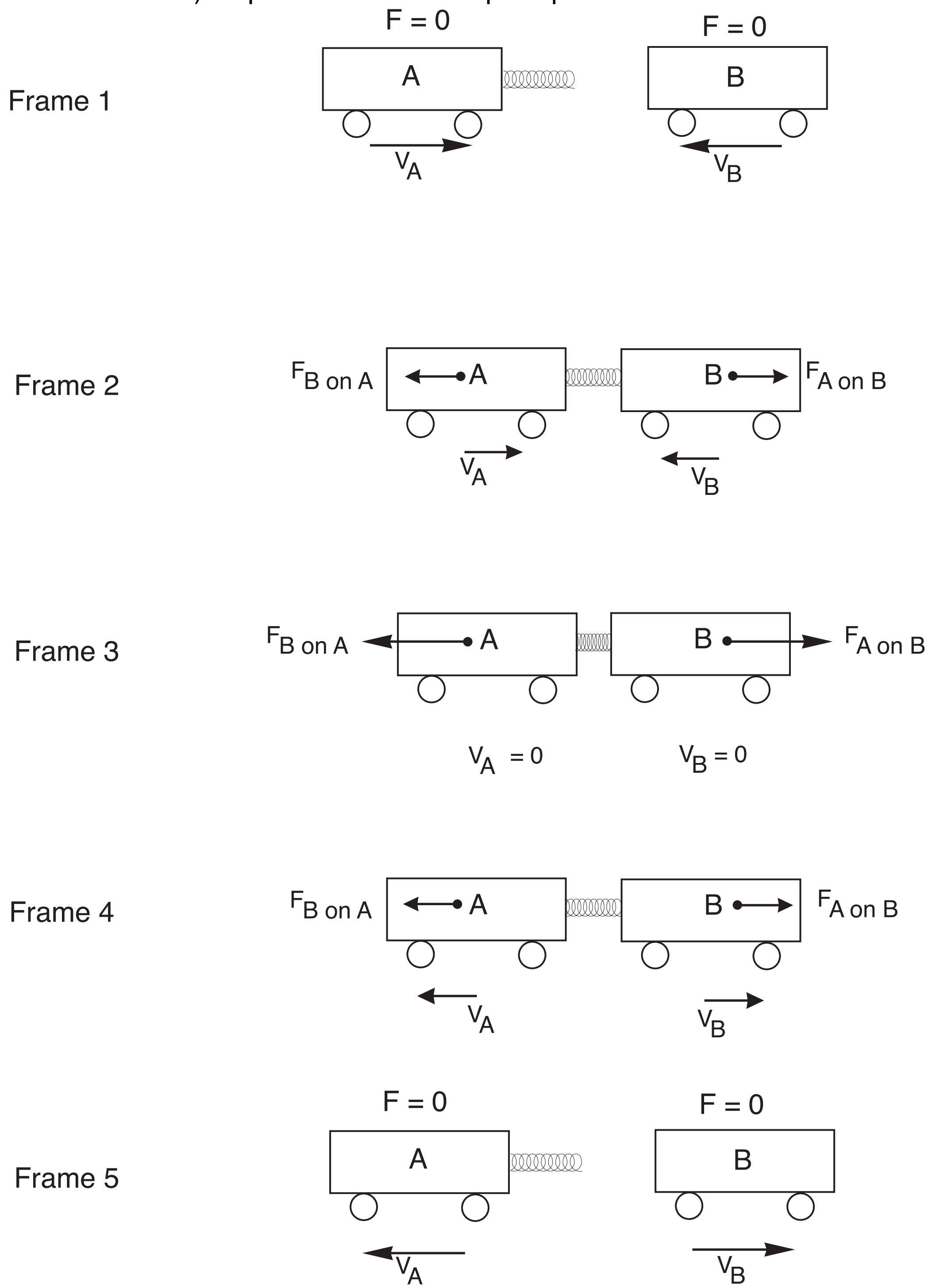
1.) Soft (weak) spring compresses more than a stiff spring so it can exert an equal and opposite force.

2.) The hard cart acts as a stiff spring and balsa wood bumper acts as a weak spring. The balsa wood compresses, balancing the force until its elastic limit is exceeded. The forces suddenly drop to nearly zero until the hard cart reaches the pile of compressed balsa wood. Then the equal and opposite forces increase once more.

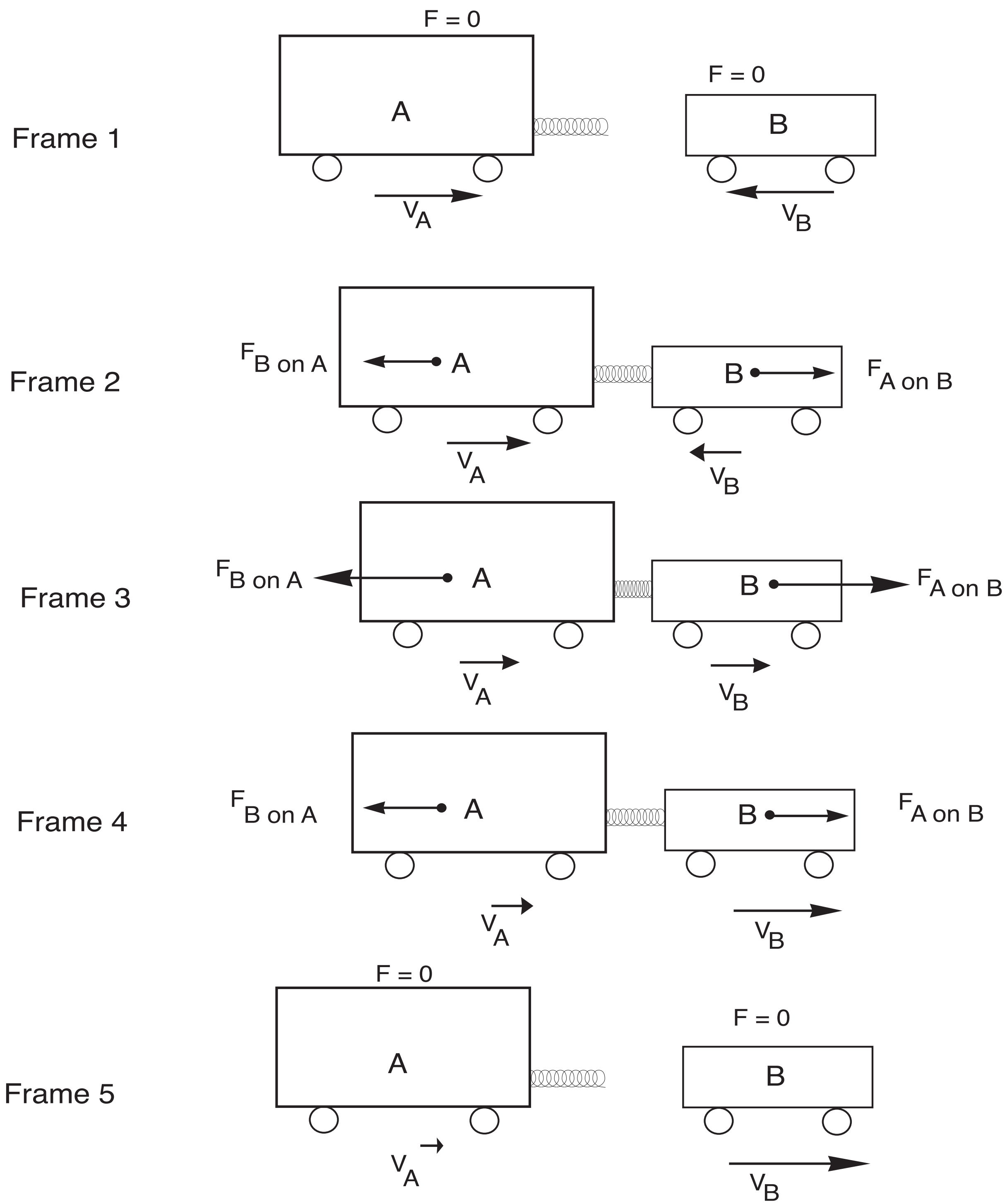
3.) Student answers will vary. Example: cart A approaches cart B at 8 m/s. This could also be seen as cart B approaching cart A at 8 m/s - or - as cart A and cart B approaching each other with both traveling at 4 m/s. The center of mass frame of reference is an interesting point from which to observe these collisions.

B. THIRD LAW IN DYNAMICS - DAY #2 - HOMEWORK ANSWERS

1.) Equal masses and equal speeds



2.) Unequal masses and equal speeds



Note: In frame 3, the point of maximum spring compression, the two velocity vectors must be equal.

C. <u>THIRD LAW IN DYNAMICS - DAY #3 - HOMEWORK ANSWERS</u>

1.) Hard cart acts as a stiff spring, and clay acts as a weak spring. The weak spring compresses more than stiff spring and deforms more. The springs in the clay do not return to their original shape.

2.) Both the fist and jaw act as springs but the elastic limit of the jaw is reached first and it breaks. When it breaks, both forces become zero.

3.) Each spring will compress enough to match the size of the force being exerted on it. If stronger, the more massive student represents a stiff spring, and the less massive student represents a weak spring. The weak spring compresses more than the stiff spring. (Note that the forces are equal, but the less massive student has a greater <u>change</u> in velocity.)

4.) Equal forces acting on the large mass of the truck and the small mass of the VW would produce a large acceleration of the VW so that the resulting velocity of the combined masses would be only a little less than 40 mph.

D. <u>THIRD LAW IN DYNAMICS - DAY #4 - HOMEWORK ANSWERS</u>

1.) **d** is the correct choice

2.) **c** is the correct choice; a and b are wrong because a force is not an internal property of an object, d and e are wrong because momentum and inertia are not forces.

3.) **g** is the correct choice; a and b are wrong because a force is not an internal property of an object, c is wrong because a force cannot be "given" to another object, d is wrong because there is no longer a force of A on B since the collision is over, and e and f are wrong because momentum and inertia are not forces.

4.) 4 m/s

5.) 3 m/s

6.) 4 m/s

7.) Diagram shows only one force vector and that is the Earth's gravitational force pointing straight down.

E. THIRD LAW IN DYNAMICS - COLLISION ANALYSIS ANSWERS

1.) Instructions.

2.) Instructions.

3.) a.) Yes, the force always produces a change in motion. The cart will speed up or slow down depending on the individual situation.

b.) Equal but opposite forces

c.) The largest forces act in frame 3 when the spring has the greatest compression.

4.) Experiment #1.) See Day #2 Homework problem 1 for a similar problem.

Experiment #2.) See Day #2 Homework problem 2 for a similar problem.

Experiment #3.) See Day #2 Homework problem 2 for a similar problem.

5.) Student answers will vary.

6.) a.) The forces increase during collision until maximum compression of the "spring" occurs and then decrease to zero when the contact ceases.

b.) Velocities are equal.

c.) The velocity of the smaller mass is changed more than the velocity of the large mass.

F. THIRD LAW IN DYNAMICS - QUIZ AND TEST ANSWERS

1.) This problem is the same as Experiment #3 in the collision analysis activity. (See Day #2 Homework problem 2.)

2.) **g** is the correct choice.

3.) Relative motion argument: From the frame of reference of the M1 carts the M2 carts are approaching at identical velocities of 10 units.

4.) This proof is done in the Day #4 lesson plan.

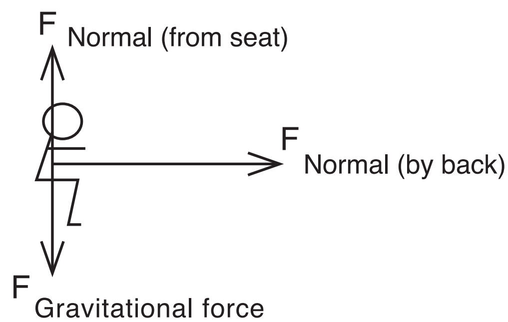
5.) Hard cart acts as a stiff spring and foam bumper pad acts as a weak spring with the weak spring compressing more than the stiff spring.

6.) a.) 6 m/s

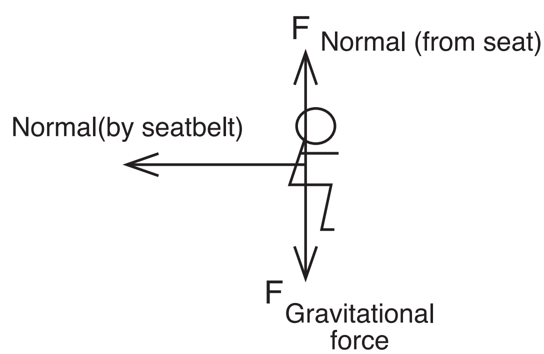
b.) Equal forces

c.) -480 kg m/s

7.)



8.)



APPENDICES

A. Additional Resources Providing Complimentary Support for Conceptual Understanding in Mechanics

B. The Use of Class Discussion and Analogies In Teaching: Examples From One Physics Classroom

Additional Resources Providing Complementary Support for Conceptual Understanding in Mechanics

Minds on Physics

Leonard, W. J., Dufresne, R., Gerace, W., & Mestre, J. (1999). *Minds on physics: Motion, activities and reader*. Dubuque, IA: Kendall Hunt.

Leonard, W. J., Dufresne, R., Gerace, W., & Mestre, J. (1999). *Minds on physics: Interactions, activities, and reader.* Dubuque, IA: Kendall Hunt.

These are excellent resources for conceptual development in Motion, Vectors, and Forces. Many activities are designed for cooperative small group work. Free body diagrams are very clearly presented, and the *Interactions Reader* is a very clear and concise summary of many types of force.

Tutorials in Introductory Physics

McDermott, L., & Shaffer. P. (2002). *Tutorials in Introductory Physics*. Addison-Wesley.

Website: http://www.pearsonhighered.com/educator/product/Tutorials-In-Introductory-Physics-and-Homework-Package/9780130970695.page, referenced 28 October 2009.

These tutorials and homework problems are designed to encourage concept development and improve reasoning skills. They are designed to be used in small classes with cooperative groups.

Physics for Everyone Project

The Physics for Everyone project offers some creative alternatives to standard physics problems. Conceptual development is emphasized.

Website: http://www.coloradocollege.edu/Dept/PC/RepresentativePhy/Pages/home.htm, referenced 14 October 2009.

Modeling Instruction in Physics

This program, based at Arizona State University, has a strong emphasis on the development of physical concepts. They have been offering excellent workshops since 1989, and a number of their leaders feel their material is compatible with "*Preconceptions in Mechanics*".

Website: http:/modeling.asu.edu, referenced 15 October, 2009.

American Modeling Teachers Association (AMTA)

Website: http://www.modelingteachers.org, referenced 15 October, 2009.

Force Concepts Inventory

This is a very popular assessment tool for issues surrounding the concept of force.

Hestenes, D., Wells, M., & Swackhammer, G. (1992). The Force concept inventory, *The Physics Teacher*, 30. 141-158.

Assessment and Curriculum

Website: http://www.Diagnoser.com, referenced 15 October, 2009

Here are interesting assessment, planning, curriculum, and teaching materials developed by Jim Minstrell. If you register as a teacher, it is available free.

Books to Consider

Laws, P. (1997). *Workshop physics activity guide: Modules 1-4.* New York: John Wiley & Sons.

Sokoloff, D.R. (2006). *Interactive Lecture Demonstrations: Active Learning in introductory physics.* New York: John Wiley & Sons.

Sokoloff, D.R. (2004). *Real time physics module 1*: Mechanics (2nd ed.). New York: John Wiley & Sons.

Thornton, R. K. & Sokoloff, D. R. (1992). *Tools for scientific thinking: Motion and force curriculum and teachers' guide* (2nd ed.). Portland, OR: Vernier Software.

Microcomputer – Based Laboratory, Equipment and Curriculum

Website: http://www.Vernier.com, referenced 15 October, 2009.

Access to Video Materials

Website: http://www.learner.org, referenced 15 October, 2009.

A number of useful video items are available free; one can open a free account and use a password to access the "teacher resources." The video items listed below are available for streaming, not downloading.

The Mechanical Universe

Minds of Our Own

Planet Earth

A Private Universe

Free Simulations and Animations

The Phet site at the University of Colorado has many interesting physics simulations and lesson plans.

Website: http://phet.colorado.edu/, referenced 15 October, 2009.

There are interesting mechanics applets at the website of Michael Fowler, Physics Dept., University of Virginia.

Website: http://galileoandeinstein.physics.virginia.edu/more_stuff/Applets/home.html, referenced 15 October, 2009.

More advanced simulations for physics and biology are available from the Concord Consortium.

Website: http://www.concord.org/resources/browse/172/, referenced 15 October, 2009.

The Use Of Class Discussion and Analogies in Teaching: Examples From One Physics Classroom

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The purposes of this appendix are: (1) to provide a real-life example of how these lessons can be used to deal with students' preconceptions; and (2) to suggest techniques for using the lessons to achieve this goal. It presents excerpts from the transcript of a class in which one of the lessons was used. The lesson plans call for a great deal of discussion by the students of the physics ideas in the domains being studied. We do not claim that whole-class discussion is the only way to teach. There are circumstances in which discussion by small groups of students is more effective, and discussion should be used in conjunction with other methods.

Group discussion is conducive to the promotion of cognitive conflict, an important facilitator of conceptual change. One form of conflict occurs between a student's conceptions (and predictions based thereon) and experimental evidence in the form of a teacher demonstration or laboratory exercise. Another form of cognitive conflict is due to two competing concepts or explanations for a single phenomenon. The latter kind is particularly evident in the case study presented in this section. Often the competing explanations come from two different students. This can stimulate some very interesting discussions and motivate students to think about key conceptual issues.

The transcript excerpted here is from a class using Unit #1 (Normal Forces). This was a physics class of about 20 students, mostly 17 years old. This public high school split first-year physics students into two "advanced" and three "standard" physics classes, and this is one of the advanced classes. None of the students had had a previous physics course. The classroom setup was not especially conducive to whole-class discussion: students sat at individual desk-chair combinations arranged in rows and columns facing the teacher at the front of the room. A semi-circular arrangement in which students could see one another as well as they could the teacher and the board would better facilitate student engagement and interaction. Nevertheless, the teacher succeeded in generating some prolonged, lively discussions.

Setting the Stage: Eliciting Initial Conceptions

The teacher's initial objective was to encourage the students to articulate their ideas about the similarities and differences between the book-on-the-table and the hand-on-the-spring situations. Note how the teacher withholds his opinion here and maintains a neutral, nonevaluative posture toward all student comments, even to the point of soliciting counter arguments to help balance the discussion.

Andrew: Well, they're similar because they're both examples of one object using force on another object, putting on force - whatever.

Teacher: Okay, so in both cases, for you at least, you see one object putting force on another object. Could you say (pause) alright, does anybody see any differences? (Waits 3 seconds.)

Beth: I see a difference in that somehow the spring has a bit of force that might throw something, and if you kind of release the spring, it would force your hand up, where the table's not going to push the book up.

Jim: There's not even any force involved to the book, it's - it's gravity, whereas the hand is not.

Teacher: That's interesting. You're saying the book is being pulled down by gravity, but we're using the muscles and the hand to...

Jim: In conjunction with gravity.

Teacher: Any other comparisons between these two situations, the hand on the spring and the book on the table, that anybody'd like to try and draw out? One involves a person, involves muscles. (Waits 5 seconds) Yeah?

Danielle: Well, they both, to a certain extent, involve flexible circumstances, but if, if you think about it, when you, when the book is on the table, that the surface of the table gets warped a little bit, and really not a whole lot, because it's wood, but if you imagine building a table out of something else, like a balloon or something like that...

In this excerpt we see a group of students working not just toward an answer that will satisfy the teacher, but toward a concept they themselves can evaluate and that makes sense to them. While an experienced teacher could, in a lecture mode, lay out the various points of view and discuss their pros and cons, here the teacher strove to elicit the conceptions from the students. The teacher's questions were very open-ended since what was asked for was not a single-word answer. He needed, and was willing to wait for, several seconds to obtain a response. The ideas expressed are not only different, but in some cases (Beth and Danielle) incompatible. Significantly, although Danielle's argument was close to the physicist's, this was not sufficient for the class to come to consensus: heated debate on this and related questions continued for another half hour. The scientist's view required time and effort for many students to assimilate.

Through such discussions, students often become aware of their partial but incomplete understanding and are able to articulate it.

Ellie: Well, the thing that I don't get, okay, I said that the book exerts - I mean, the table exerts a force on the book only because some time in past life I heard somebody say something like that, but-- I understand about the spring because when you compress the spring then it has to uncompress, so it's pushing up on your hand, because it doesn't like being compressed, it's not a compressed thing. So I get that, that's really clear. But the book, you're not, you're not, you're not changing the table when you, when you put the book down.

Students Not Only Expose Their Uncertainties, But Begin to Ask Questions to Help Them Frame the Problem at Hand

Frank: In the second situation [the hand on the spring], are we considering just the force of the hand on the spring, or also the spring on the table?

Grace: Well, what happens if you have a really mushy spring?

Howard: Is it necessary that you use your hand instead of the book on the spring?

These questions are spontaneous and are not intended to satisfy a specific request from the teacher. Such questions, as well as statements of belief or opinion, can also provide diagnostic information for the teacher.

Students Propose Models and Construct Arguments

After spending some time expressing initial ideas and asking questions, students begin to construct and articulate their own arguments concerning the problem at hand, including arguments against the physicist's view.

Irene: If the table is perfectly rigid, you could almost call it part of the ground, if it's not going to move. I mean, sure, if the book - if the table isn't there, it [the book] is gonna hit the ground, but you could always dig a hole, right? If you dig the hole, you're going to say the ground is moving too? So you dig the hole, and it falls again? You could dig all the way to China, it keeps falling.

Irene attempts to counter another student's argument (that the table must exert a force because if the table weren't there the book would fall) by invoking the Earth in its full depth and mass as an object that is even less likely than the table to be exerting an upward force, and that would not necessarily allow the book to "fall" in one direction. Although it led to the wrong conclusion from the physicist's point of view, this is an impressive example of generating an argument via a hypothetical experiment. Soon enough, its pertinence is challenged by another argument.

John: Does it matter whether it [the table] moves or not? Isn't the point just that it's holding it [the book] in a position that it doesn't want to be in? I mean, if you took the table away it would fall down. The table's holding it up whether it moves or not.

At this point Larry jumps in.

Larry: But it-- is that a force necessarily? There's got to be a force if it's (interrupted by general heated discussion among students)

While it is clear that student involvement here is very high, from the perspective of some teachers, discussions like this (or questions from students as in the previous section) can lead to too much divergence. Depending on his or her objective at that moment, the teacher can guide the students toward a more focused, concentrated discussion, or broaden it, going in a new direction or bringing in new ideas. In this case the teacher chose the former path.

Teacher: That's an interesting argument but-- I do want you to keep in mind [that] the earlier question was: is the table pushing up on the book? That is still a piece of what we're fighting about.

A Student-Generated Bridging Analogy

The teacher then introduced the bridging analogy of the book on a soft foam pad. After some discussion, one student suggests the following.

Karen: Wouldn't it make more sense if we built the table out of something pliable--

She is interrupted by several other students who comment on the idea.

Larry: Like plywood.

Maria: A piece of cardboard.

Nelson: Or a piece of paper.

Olivia: Bounty. [The brand of paper towels.] (Laughter)

Karen actually foresaw the bridging analogy the teacher had planned to use! The class was ready for it: other students added ideas and questions, and this set off several minutes of sometimes heated exchanges in which almost the entire class took part. Students began to describe more complete models of the situation. Pam compared a "bendy" table and a "hard" one.

Pam: In both cases, it's the exact same table, the exact same amount of force at that, at that line [the boundary between the book and the object it is resting on], except with the bendy table, it's just magnified more, so you can see it, and on the other table, the hard table, it's just an insignificant amount of movement, but it's an equal amount of force.

Even with this relatively clear articulation of the "correct" point of view, there were many students who were far from convinced. Ross immediately retorted:

Ross: So what do you call an insignificant amount of movement - none?

Students Propose Intermediate Models as "Stepping Stones"

After a few more minutes of lively discussion, Sondra proposed another view.

Sondra: My theory is that any object has a shape and size attached to it, and when you apply a stress to it, it changes that, the object will try to go back to its original shape. So the spring will be exerting a force to go back up, so it could go back to the size it's happy with. The table has a certain shape it's happy with, and if you put a book on it, it will try to bend the thing, so the table will apply a force back up.

Although it invokes the informal metaphor of a human-like "will" for the table, Sondra's argument was convincing to most of the class. It provided a first step toward a model of elastic deformation of solids initially at rest when acted on by a force. Although it is not an expert model, it is important to recognize the value of such intermediate models as "stepping stones" toward more sophisticated models.

Like many students' models, Sondra's was couched in her own words and images. Tina used her own words to invoke something the class had learned the previous year.

Tina: Remember like in chemistry, you look around, you can't see it, but you look on it, the atoms are actually bending, but not much, it's not like you can say well, it moved, I saw it move, but it *does* happen. It is a force that's there, everything has to be there.

After 30 minutes of vigorous discussion, the teacher proposed a molecular explanation similar to Tina's, of course with a bit more polish, and expressed in more global terms. The great majority of students now seemed ready to accept this argument and indicated that it made sense to them. In subsequent weeks, they frequently referred to this model of contact forces.

The Importance of Students Constructing and Evaluating Models

The teacher could have presented this explanation right from the beginning. The students would probably have "accepted" it in the sense of finding ways to remember it, at a verbal level, for retrieval at the next exam. But in light of their preconceptions, it would not have made sense for many of these students. In a classroom discussion led by a skillful teacher, students **evaluate** assertions and explanations of their peers, and actively try to make sense of these as well as of the explanations heard from the teacher and read in the book. This contrasts with passively accepting ideas on the basis of authority. This kind of active "self-evaluation" is extremely important in areas such as science where students are likely to have or develop alternative conceptions due to the complexity or counterintuitive nature of the material. Students must construct, evaluate, and improve their models several times, since they rarely construct the correct model on the first try, even with the benefit of a "clear and complete" exposition in lecture form.

Deeply-held conflicting preconceptions are not usually changed by arguments coming solely from an outside authority. Only by coming to understand the various arguments for and against the competing models can students change their conceptions. Individual students are less likely to come up with more than one model or explanation. A special value of class discussion is that in an open discussion the chance is very good that many models, including one that is in agreement with current scientific theory, are actively evaluated by the *students*, and that the distinctiveness and plausibility of the physicist's model can be appreciated at a "makes sense" level as well as at more formal levels.

Summary

Group discussion can be a powerful teaching tool when facilitated by the teacher's open-ended questions, temporary withholding of answers, wait time, and nonevaluative stance. Student responses that were encouraged and valued by the teacher include the following:

Students

- Identifying specific gaps in their own understanding;
- Asking clarifying questions for the group;
- Proposing models and constructing arguments and thought experiments;
- Generating analogies and bridging analogies;
- Proposing intermediate models as stepping stones;
- Evaluating models and arguments by focusing on whether they "make sense."