RESOURCE KIT FOR THE NEW PHYSICS TEACHER

Developed by the American Association of Physics Teachers 1985

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The purpose of this Resource Kit is to provide new physics teachers with information and materials that will help them actively involve their students in the process of learning physics from the first day of school. The materials in this kit can be used during the first few weeks of an introductory physics class. After the help provided by this kit, we hope that teachers will have gained enough confidence to procede on their own through the rest of the course.

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EDITED BY JIM NELSON -- VISITING FELLOW AAPT 1984 - 85

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Starred(*) items may be reproduced and used as student handouts.

I. WELCOME TO THE PROFESSION

So you've going to teach physics this coming year and you're not ready? Perhaps you took one or two physics courses in college, but even that was years ago. Or perhaps you are a new teacher. Your predecessor has left you a legacy of jumbled equipment which you don't recognize. Yet you're going to have some of the school's best students in your physics class and you want to do a good job, even if your heart belongs in another field.

If this describes you, this resource kit is designed to help you get started. It has been developed by a group of high school teachers who are members of the American Association of Physics Teachers(AAPT). Many of us have had your experience and have survived the same frustration and anxiety you're probably feeling now.

In this kit you'll find specific ideas and materials relating to the beginning weeks of a typical high school physics course. But first we want to suggest two ways you can obtain some very helpful person-to-person aid.

First if you still have some free time ahead of you, consider attending a physics teacher workshop. Workshops are being scheduled all across the country by teachers trained by AAPT to be Physics Teacher Resource Agents. This effort is in response to the present critical shortage of well-trained physics teachers. Your administration should be able to get information for you and provide assistance so you can attend a workshop. If you need assistance call your state science supervisor or contact Jack Wilson, AAPT suite 101, 5110 Roanoke Place, College Park, MD 20740 (301) 345 - 4200. A workshop won't solve all your problems, but you'll meet fellow teachers, get good ideas and begin to build your confidence.

Second you can latch onto an experience physics teacher in your area who may be able to visit you and go through your laboratory and storeroom with you. This teacher could identifying mysterious items and pointing out what you should use in the early weeks for demonstrations, experiments, and student motivators.

He or she will also be at the end of a telephone line when you're asked a question you can't answer, or when you need further suggestions, explanations, or support throughout the year.

If it isn't obvious where such a pargon pal is to be found, it is time for your first contact with AAPT -- the American Association of Physics Teachers. In the supplementary materials that comes with this kit, you'll find information about the services and products that AAPT has to offer, but for the moment you should contact Jack Wilson at the AAPT Executive Office, Suite 101, 5110 Roanoke Place, College Park, MD 20740 (301) 345 - 4200. Ask for information about high school physics teachers that are members of AAPT and live in your area. The association staff will almost certainly have some suggestions for you. We may know of a high school teacher who is active in your regional AAPT section, or if not, a section officer who may be able to suggest the right person for you. There are also college teachers, identified in a recent AAPT project, who are willing to lend a sympathetic hand to high school teachers, and one of them may teach at a college near you.

Once your AAPT section knows about you, you'll be invited to attend section meetings. There you'll find an informal fellowship among people at all academic levels who love to teach physics and want to do it better. Do try to go at least once, to see what it's like.

Please don't be shy about asking for aid, or embarrassed to confess ignorance. Remember that every single one of us has been there -- and still do find ourselves there from time to time!

When it comes down to the hard question of how you are actually going to teach this course, there is an important decision for you to make. Chances are you have inherited whatever textbook your predecessor used, and of course it is going to be your guide throughout the year. But are you going to let it take over the course from you? In desperation you may be tempted to ignore that equipment in the storeroom and take the easy way out: i.e., "For tomorrow read sections 1 - 5 and do problems 1 - 8."

Resist! You and your students can learn physics by doing physics in many different ways, only one of which is reading what the textbook has to say. After all, physics is a wonderful adventure of the human mind and spirit. Resolve to make the learning process an adventure you share with your students, mishaps, pitfalls, and all.

An AAPT committee of high school and college teachers is designing a physics syllabus for secondary schools which should be of special help to someone who is a beginner. This group recommends the "phenomenological approach" to physics teaching. This means tying every physical law and concept to concrete examples with which students are familiar through everyday experience, laboratory experiments, demonstrations, or films. We warmly endorse this suggestion, which is rooted in sound learning theory. We hope you'll give this approach a try! The materials in this kit are designed to help you understand and use this approach. We think you'll find it more fun and more successful than a read-the-book-and-memorize-the-formula approach.

It is realistic to predict that most students will forget a great deal of the content of any course shortly after they finish the final examination. But physics is much more than a body of knowledge. It embodies habits of thought, philosophical attitudes, broad concepts, and basic skills that can be developed slowly all year and can last a lifetime.

For example, you can help students learn that <u>what</u> they know is no more important than <u>how</u> they know it and how <u>well</u> they know it. You can teach this by stressing observational evidence, logical reasoning, and the assumptions, idealizations, and uncertainties that underlie the "facts", the laws, and the theories of physics. The worksheets that are included in this kit are designed to help students follow the reasoning that leads to a particular conclusion, including its uses and its limitations. By the end of the course you hope that students will have become more skeptical of the "scientific proof" claims of advertisers, astrologers, and the like.

We've included in this kit materials we though would be most helpful to you. If they are not, or if there are things we left out that you would have liked, please write to Jack Wilson at the AAPT Executive Office with your suggestions. Good luck, and welcome to the profession!

II. GETTING STARTED

A. Writing an Information Package for Students

Many physics teachers explain their policies in writing rather than by lecture on the first day or two of class. Students want to know how you grade, what kind of tests you give, and what is expected of them in the way of assignments and procedures. You'll want students to know when you will be available for help, about safty in the laboratory, about coming to class prepared with assignments and materials, and about making up work after an absence.

These concerns are much the same in physics as in any other discipline, and what you say will depend on your own style of teaching. There are, however, some techniques used by many successful physics teachers which you might like to consider.

1. A flexible grading system that awards points not only for required tests, assignments, and laboratory work, but also for optional work that allows students to use their strengths to make up for their weaknesses. For instance, a student who is shaky in mathematics, but a whiz at electronics or art or shopwork, could be a big help to you and earn credit by doing so. Other options for extra credit are outside reading, writing computer programs, reports on science related experiences, setting up demonstrations, building equipment, making posters, et cetera.

2. Open book or open note tests. This puts the emphasis where it belongs: on understanding concepts rather than rote memory for facts and formulae. When students are allowed to bring one page or a 3 x 5 card of notes that they have written themselves to a test, they tend to study more effectively as they organize and synthesize what they have learned. Some teachers, however, do insist on some memorization of essential tools of the trade, such as definitions of physics terms.

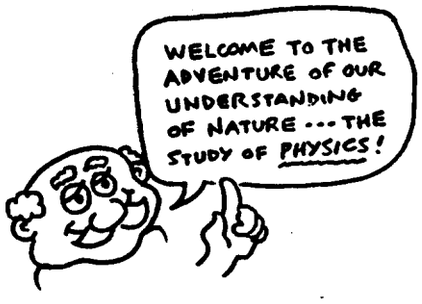
3. Students are often asked to provide their own metric rulers, protractors, drawing compasses, pencils, pens, and graph paper -- all required tools of the trade. Physics students can't go far without them. As often happens, students forget to bring what they need to class. If you have supply of rulers, et cetera on hand, you can lend them, rent them, or sell them, and things will go much more smoothly. Before selling anything to students, be sure and check your school policy.

4. Calculators? Yes, encourage students to bring and use them, and if possible, have a few available for loan. They're great time-savers, but students should be made aware of the hazards: too many significant figures, too easy to accept a wrong answer from a careless entry, and no record of what you did to arrive at an answer. Learning the art of estimation (See section V, part C) early will help students avoid accepting calculation mistakes.

5. Tips for students on success in physics. Here is what one teacher puts in an information packet:

> I. Keep an organized notebook, looseleaf preferably, since you will receive many handouts.
>
> II. Physics is a new subject, and like anything new it takes getting used to. Be patient and you'll soon get the hang of it. Sure it's hard sometimes, so you can be very proud of yourself when you do well.
>
> III. Get involved! Don't just sit there! Ask questions! Push a pencil! Discuss physics with your classmates and friends. Help each other.
>
> IV. Don't let yourself get behind. It's too hard to catch up!

B. Day One: Off in the Right Mood and on the Right Foot



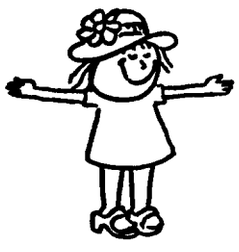
Many students come to their first physics class very nervous about how they are going to do. If it's any comfort to you, they are even more apprehensive than you are.

Why not postpone issuing those intimidating textbooks for a day or two and plan something to ease the panic and make everyone feel more at home?

For instance, you could take everyone on a get-acquainted tour of the classroom and laboratory. Put out some of the interesting equipment you find in your storeroom, and ask the students what they think it's for. Or you could stage a treasure hunt for "treasures" having to do with either measurement or motion. Why measurement and motion? They are almost invariably the lead-off topics in physics textbooks. The hunt will give your students a chance to observe and to think about their observations before they read about them -- a general procedure that you and your students might follow all year long. If you think you might like to try the treasure hunt, you'll find a sample treasure hunt worksheet on page 10.

Alternatively, you might spend the first class, after the initial formalities are over, checking your students' feel for the metric units of length, mass, and time.

LENGTH: Ask students to show you, with spread arms or fingers, how long they think a meter is, a centimeter, a millimeter, et cetera. Get students to estimate some distances -- the length and width of the classroom; the diameter of a pingpong ball; the thickness of a notebook. If meter sticks, rulers, or tape measures are available, students should check their estimates.



Ask students to find the thickness of one page of a book (measure 200 numbered pages and divide by 100). What do you call one thousand meters? (A kilometer, with the accent on the first syllable). How do they think a kilometer compares to a mile? (1 kilometer = 0.62 mile; 1 mile = 1.61 kilometer.) If any students have spent some time in a country using the metric system, ask them to comment.

MASS: Pass a kilogram mass around so students can get a muscular sense of its heft. (A kilogram weights about 2.2 pounds.) Ask students if they know how a gram (symbol = g) is related to a kilogram (symbol = kg) Note these are symbols and not abbreviations, thus no period is used after the symbol.

$$1000 \text{ g} = 1 \text{ kg}$$
$$1 \text{ kg} = 10^3 \text{ g}$$

Can students suggest any common objects with about a one-gram mass (paper clip, dollar bill)? or five grams (a nickel)? et cetera.

Be sure you say "mass" rather than "weight" when talking about grams and kilograms. There is a difference that is important in physics. The weight of an object is the pull of gravity on it. It is a force that varies from place to place, and physicists measure force in newtons rather than pounds. Although variation in weight is trivial as you move around on the earth's surface, the variation is very significant if one moves from the earth's surface to the moon or other points in space. On the other hand, mass is an intrinsic property of an object that does not depend on where it is located. Unfortunately, the pound unit does not distinguish between mass and weight. A pound sometimes implies a mass (equivalent to about 0.45 kg), and sometimes implies the weight of that much mass (equivalent to about 5 newtons). It's very confusing, so stick to kilograms! You'll get to newtons later.

TIME: The second is a familiar unit, but students might enjoy knowing that they can measure to the nearest fifth of a second without a stopwatch. This is done by saying, rather fast, "ALLIGATOR-one, ALLIGATOR-two ALLIGATOR-three..." Or perhaps "Mississippi-one, Mississippi-two, Mississippi-three..." Don't pause at the commas! If you have a clock with a sweep second hand, count to ten the alligator way while the class checks the rate. When it's done right, it takes one-fifth second to say each syllable. Better practice in advance!

How long does it take for something to fall from shoulder height to the floor? Just say "AL" as you let go, and note what syllable you're on when the object hits the floor. (2/5 second for "LI", 3/5 second for "GA", et cetera). Students with digital watches might like to see how much better they can do. Do all the measurements agree? If not, this is a good time to point out that all measurements are uncertain to some degree. There is a reference in the appendix called "WHAT'S REALLY IMPORTANT TO KNOW ABOUT MEASUREMENT!" This appendix discusses important concepts about measurement. The concept of measurement is so basic to all science that it is good to stress it over and over during your course.

This would also be an appropriate time to make clear the relationships between prefixes and powers of ten used with metric units. The prefixes mentioned so far, centi- and milli-, are both subdivisions of a unit. Centi means one one-hundredth of a unit, thus:

1 centimeter = 1/100 meter = 1×10^{-2} meter

Milli is the prefix for one one-thousandth; thus:

1 millimeter = 1/1000 meter = 1×10^{-3} meter

Kilo- is a prefix and means one thousand.

1 kilometer = 1000 meters = 1×10^{3} meters.

Other prefixes that students will need to know are discussed in the appendix. If you find students need help with powers of ten notation, there is a handout in Section V, part A with rules, examples, and practice problems on power of ten notation.

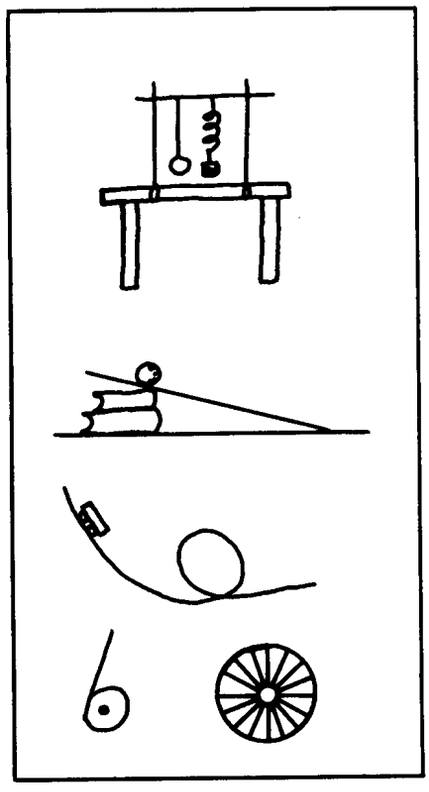
If you choose to adopt any of the day-one scenarios suggested above, you may find the sample worksheets or homework assignments on pages 13 & 15 useful. These require no textbook reading -- just thought. Feel free to copy them (or anything else in this Resource Kit that you can use as a hand-out). If you have time, students could start the assignment in class. You should circulate to give individual help where needed. Looking over the student's answers should give you a good idea of your students' understanding.

In case you want to try the Treasure Hunt option.....

On the next page you will find a Physics Treasure Hunt worksheet. You can reproduce this or adapt it to your situation. Here are a few ideas for setting up a physics treasure hunt in your laboratory or classroom.

Look for these items in your laboratory:

1. Meter stick, yard stick, and kilogram mass. (These should be handy for reference only; out-of-bounds for the treasure hunt.)



2. Metal rods and clamps to fasten onto a table as a framework to hang things on. You should have these things, but if you don't, borrow from chemistry teacher or improvise.

3. String and pendulum bobs (any object you can hang up will do).

4. Springs and different mass objects to hang on the springs.

5. Grooved rulers or somthing to act as a track. Metal balls or marbles to roll down the track. Books can be used to prop the track up.

6. Tennis, pingpong, or superballs for bouncing. A nerf (i.e. soft foam ball) ball tied to a string for whirling around.

7. An inclined plane (wide, smooth board you can prop up at one end), and a cart or cylinder to roll up and down the incline.

If your storeroom is well supplied, you may also find some of the following wind-up tractor; turntable; bicycle wheel; hot wheels track and car; gyroscope; top; strobe light; air track with floating gliders; metronome; yo-yo.

NAME OF STUDENT: _____

DATE: _____ PERIOD: _____

PHYSICS TREASURE HUNT

When you find each item, write it down next to the description.

A. MEASUREMENT:

1. Find something that is about one meter long, wide, or tall.

2. Find something that is about one centimenter long, wide, or tall.

3. Find someone who is about 1.7 meters tall.

4. Find something with a mass of about a kilogram.

B. MOTION:

5. Find three objects that repeat their motions over and over in equal time intervals.

6. Find an object that repeats its motion about once a second.

7. Find something that will move for a short distance with nearly constant speed in a straight line.

8. Find something that starts from rest and steadily increases speed until it hits something.

9. Find something that will fall without increasing speed all the way down.

KEY FOR PHYSICS TREASURE HUNT

These are some of the possible answers students could use .

A. MEASUREMENT:

1. ONE METER DISTANCE: metal support rod; height of laboratory table or stool; distance from a student's belt to the floor

2. ONE CENTIMETER DISTANCE: paper clip; dime; little fingernail

3. SOMEONE 1.7 METERS TALL: This is about 5 foot 7 inches

4. ONE KILOGRAM MASS: physics book; pair of 500-gram masses; cart

B. MOTION:

5. MOTIONS REPEATING IN EQUAL TIMES: pendulum swing; mass vibrating on a spring; rotation of clock hand or turntable; heartbeat; breathing rate

6. MOTIONS REPEATING ONCE A SECOND: 25-centimmeter pendulum; certain mass vibrating on spring; heartbeat

7. SOMETHING MOVING WITH CONSTANT SPEED: marble rolling along smooth flat surface; wind-up car; student walking; toy tractor

8. SOMETHING MOVING WITH INCREASING SPEED: falling object; object rolling down hill

9. SOMETHING FALLING WITHOUT INCREASING SPEED ALL THE WAY DOWN: sheet of paper; nerf ball; feather; marble falling in glass of water

NAME OF STUDENT: _____

DATE DUE: _____ PERIOD: _____

WORKSHEET ON MEASUREMENT

1. A football field is 100 yards long. Is that more or less than 100 meters? Explain your reasoning!

2. Is "centipede" an appropriate name for an insect with lots of legs? Explain your reasoning!

3. True or false: A millisecond is about 17 minutes. Defend your answer!

4. The weight of a one kilogram object on earth is about 2.2 pounds. Would ten pounds of potatoes be closer to 22 kilograms or 4.5 kilograms? Explain your reasoning!

5. A kilometer is about 0.6 miles. If you were arrested for going 100 kilometer/hour in a 55 mile/hour zone, and the fine was $30.00 for each 5 miles/hour over the speed limit what would be your fine? Explain your reasoning! (Note: In Canada the speed limit is 100 kilometer/hour.)

6. Verify: 1 hour = 3.6×10^3 seconds

   1 24-hour day = 8.64×10^4 seconds

   1 year is approximately 3×10^7 seconds

Here are several other metric prefixes that you will encounter in physics. You will need them for your next assignment.

	prefix	symbol	factor	in words
Big ones:	mega-	M	10^6	a million
	giga-	G	10^9	a billion (pronounced jigga)
	tera-	T	10^{12}	a million million)
Little ones	micro-	μ, Greek letter mu	10^{-6}	a millionth
	nano-	n	10^{-9}	a billionth
	pico-	p	10^{-12}	a trillionth (pronounced peeko)

7. What can you think of that is worth a megabuck? What do you call 10^{-9} goat?

KEY FOR WORKSHEET ON MEASUREMENT

1. A yard is about 3.4 inches shorter than a meter, so 100 yards is less than 100 meters by 340 inches, or about 28 feet.

2. No. If you used metric prefix, a centipede implies 1/100 leg. Of course the word centipede is not a metric unit!

3. False. A millisecond is only 1/1000 second. 17 minutes is about a kilosecond.

4. Closer to 4.5 kg. 1 lb is the weight of 0.45 kg, so 10 lb is the weight of 4.5 kg.

5. (+) 100 km/hour x 0.6 miles/km = 60 mi/hour. Fine will be $30.00!

6. (+) 1 hour x 60 min/hour x 60 seconds/min = 3600 seconds

   1 day = 24 hour x 3.6 x 10^3 seconds/hour = 8.64 x10^4 seconds

   1 year = 365 day x 8.64 x 10^4 seconds/day or about 3 x 10^7 seconds

7. Megabuck: diamond necklace; mansion
   10^{-9} goat = 1 nanogoat. (If you can stand it, there is a whole page of these in the appendix!)

(+) If students are unfamiliar or uneasy with the factor label method used to solve problems 5 and 6, the worksheet in Section V will prove helpful.

NAME OF STUDENT: _____

DATE DUE: _____ PERIOD: _____

WORKSHEET ON MOTION

The study of motion is called kinematics. Kinematics has to do with how to define, describe, and classify motion. Below there are some descriptions of some simple kinds of motion. From your experience, list examples that are typical of each description.

1. Moves at constant speed in a straight line.

2. Moves at constant speed in a circle.

3. Moves at decreasing speed until it stops.

4. Moves at a constantly increasing speed.

5. Moves up and down or back and forth with speed alternately decreasing and increasing in a regular way.

6. As you look over the descriptions above, what words and ideas seem to be essential in describing motion?

7. The speed of light is 3.00×10^8 m/s. How far does light travel
   (a) in a microsecond?
   (b) in a picosecond?

   Hint: multiply distance/time by time to get distance.

KEY TO WORKSHEET ON MOTION

For questions 1 to 6, other answers are possible!

1. Hockey puck; car on freeway; wind-up toy car; student walking; marble rolling along a smooth flat surface

2. The edge of a turntable, teeth on a circular saw, horses on a merry-go-round

3. Anything coasting on a level surface, car with breaks applied

4. Bodies which are falling, or coasting down hill

5. Bouncing ball; swinging pendulum; object vibrating on a spring

6. SPEED: whether constant or changing; possibly whether fast or slow
   DIRECTION: whether constant or changing

7. (+) (a) $d = 3 \times 10^{8}$ m/s $\times 10^{-6}$ s; $d = 3 \times 10^{2}$ m = 300 m

   (+) (b) $d = 3 \times 10^{8}$ m/s $\times 10^{-12}$ $d = 3 \times 10^{-4}$ m = 0.0003 m = 0.03 cm = 0.3 mm

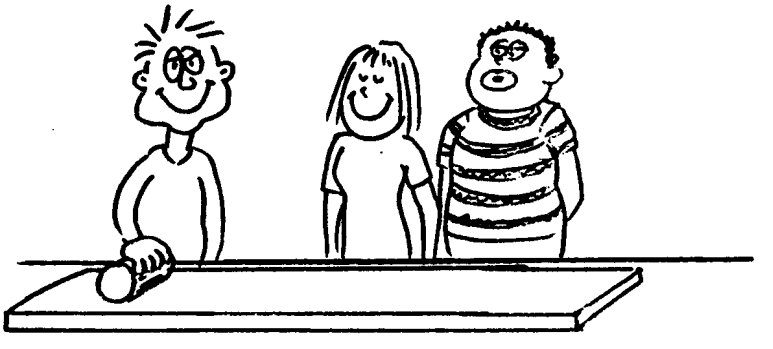
(+) If students are unfamiliar or uneasy with the factor label method used to solve problem 7, the worksheet in Section V will prove helpful.

C. DEVELOPING THE CONCEPT OF SPEED

Having spent the first day or two getting comfortable with metric measurement and looking at the different ways in which objects move, students should be ready to put the two together. You've noticed that they'll watch anything that moves, so take advantage of the opportunity by setting up a simple motion you can all watch together, and then apply measurment to it.

The simpler the arrangements, the better. Use a smooth and true metal cylinder as your moving object. A can of food that doesn't slosh around inside would be good, or a large hooked cylinder (500 g or 1 kg). Find a smooth, flat board. The kind you probably have in your storeroom for inclined plane experiments would be fine, or any other straight flat surface about a meter in length and perhaps 15 cm wide. You could also use a wind-up or battery toy tractor.

First set things up so that in your judgment the cylinder, once started, rolls very slowly along the board at constant speed. You may need to put a couple of file cards under one end of the board to compensate for air and rolling friction slowing the motion slightly.



Ask students to describe the motion. Chances are they'll say it's slow, and perhaps even. See if you can get them to explain in simple language what they mean by "slow" or "even" or other descriptive words. Educational research indicates that students intutively grasp the idea of speed before they can relate it to its components of distance and time.

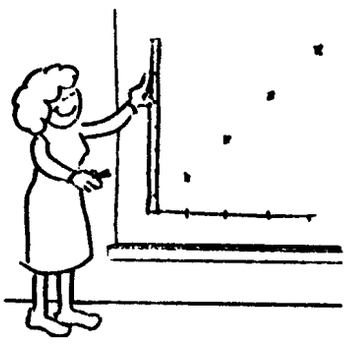
Arnold Arons, in a recent series of articles in The Physics Teacher magazine (December '83, January and February '84), discusses how verbalizing helps students move from a fuzzy idea to a well-defined physical concept.

Once distance and time have entered the discussion, measurement becomes appropriate. Use a crude timer, like a slow metronome, a pendulum a meter or more in length, or even have the class do the alligator count (see page 7).

Have one student put chalk marks on the edge of the board to show the position of the rolling cylinder at successive equal time intervals. Another method to mark position is to place small objects at the position of the moving object each time a count is made. The chalk mark can then be made on the board at the position of these objects. After you've put the cylinder in motion, start counting -- zero, one, two, three... Unless you find a way to make the cylinder roll at the same speed each time, all measurements must be done at a single trial.

Now compare the distances the object has moved in the equal time intervals. The distances between the marks look equal. The times are the same, and what else seems to be constant? Talk about speed with reference to pitched baseballs, bowling balls and other objects with (nearly) constant speed. At this point don't do any calculations; just get students to verbalize their ideas. Is the four minute mile a measure of speed? How about one-fourth mile/minute, or 15 miles/hour? One gives the time required to travel one unit of distance, while the other gives the distance traveled in one unit of time. Both descriptions are ratios involving distance and time. Is one preferable to the other, or more commonly used?

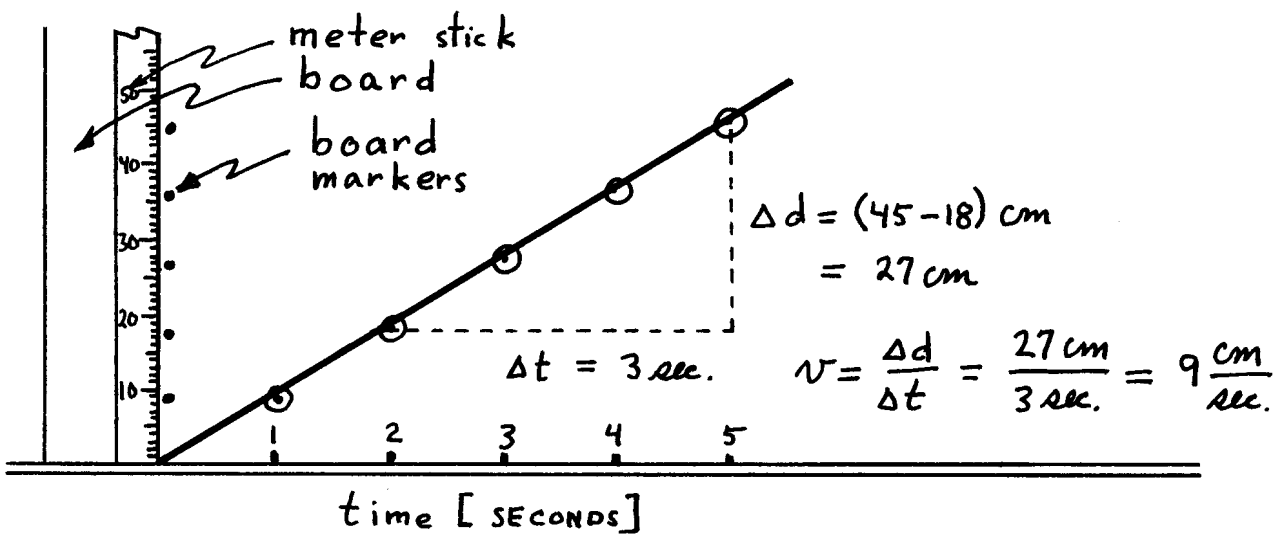
After this verbal approach, the next step in developing the concept of speed is to convert the position and time data you have taken into a graph.



Rest the board on the chalk tray and stand the board with the marks on its edge, vertically against the blackboard. Use the edge of the board as a ruler to draw the vertical axis for a graph, on this axis mark the positions of the cylinder at consecutive times.

Draw the horizontal axis through the first marked point on the board, and indicate the time divisions on it, using clicks, swings, counted seconds, or whatever unit you used for time. Make the graph about as wide as it is high.

By extending lines up and over locate the data points, making sure students understand this process. To some of them this will be old stuff, but a few may never have done it. How is the best line for a graph determined? There is a reference on drawing and interpreting graphs in the appendix which you probably ought to review ahead of time. It's too soon to give it to students, but you should talk about the graphing techniques as you do them.

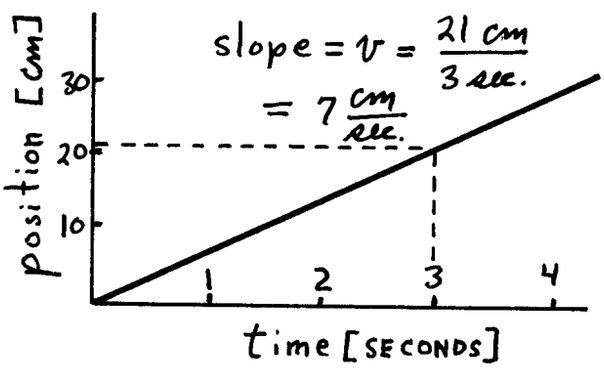


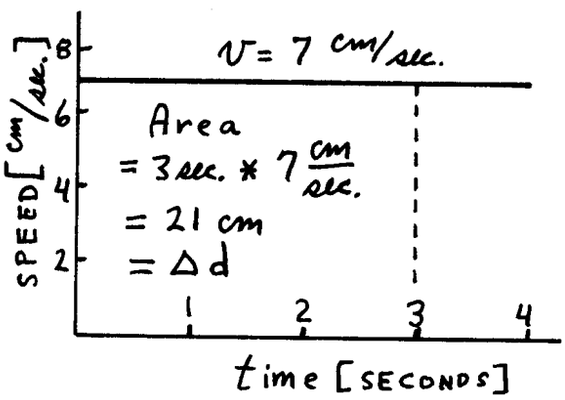
The graph of the uniform motion will be straight (with an expected scattering of points due to uncertainty of the measurements). Explain the significance of the constant slope of the line, and thoroughly review with students the definition of slope. (Slope is the vertical rise over a corresponding horizontal run, in this case Δd over Δt.) They must also know the meaning of Δ.(1) Emphasize that the Δs must be found by reading the scales for position and time, including their units. Using a ruler or counting squares will not do for finding rise over run for use in physics equations.

(1) Δ is the Greek letter delta. It corresponds to the letter D in our alphabet, and it indicates <u>difference</u>. Δd is read as "delta d, and is calculated by using $d_f - d_i$. Note: the change is always the final value minus the initial value. Δd is called the displacement. If d_i is zero, the displacement is equal to d_f and this is often called distance. In a similar manner Δt is $t_f - t_i$.

Before you calculate the slope of your blackboard graph, it would be a good idea to add a vertical centimeter scale next to the board mark scale. Including the units in the calculation of slope leads inescapably to the conclusion that the slope of a position versus time graph represents speed. (The common symbol for speed is v.)

Now repeat the experiment at several different speeds. Before plotting the new points, see if students can predict what the new graphs should look like. They will still be straight lines, but the faster speeds will have steeper slopes.





Ask students to sketch a speed versus time graph for one of the experiments. It should look like the right hand sketch above. Now comes a concept that is probably new to everyone: the area under a graph. When you start with a position versus time graph, its slope gives you the speed. But when you start with the speed versus time graph, the area gives you back the displacement (i.e. Δd). Try it. Pick a time -- say three units -- and draw a vertical line up until it intersects the graph line. The area enclosed is a rectangle with base 3 seconds and height equal to 7 cm/sec. The speed multiplied by the time gives the displacement traveled in that time, and thus gives a point on the position versus time graph.

Care must be taken to distinguish between position; displacement; and distance!

<u>Position</u> is an indication of where an object is at any instant. A marker can show position. For example the spots on a strob photograph or made by a vibrating timer.

<u>Displacement</u> is the length (and direction) of a straight line drawn from one position to another. Displacement is represented by delta d.

<u>Distance</u> is the length of any path followed by an object. This is rather like the odometer reading of a car.

On the next page is a worksheet to help reinforce the techniques and conclusions you hope students will learn from this class experiment and discussion. A short sample quiz is also on page 27. What you do beyond this point depends on the experiment you have planned for the next topic. You don't want to spoil the students' experiment by doing it as a demonstration. If, however, there is not much overlap, you can use the same techniques to introduce accelerated motion. This next step is discussed in Section IV.

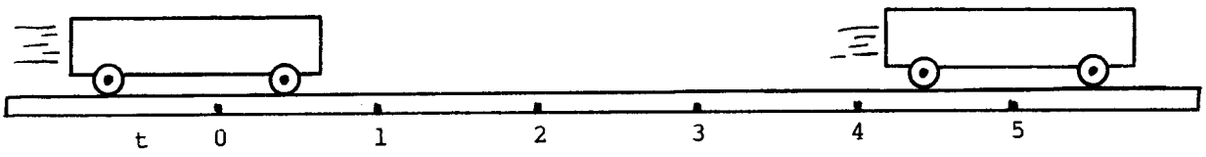
If you are in need of a more extensive review of graphical techniques, study what your textbook has to offer. If that doesn't do a good job for you, it surely won't for your students. Graphical analysis is such an important skill for physics in particular and all science in general that you need to become very confident about it yourself to transmit it to your students. Your buddy or your librarian should be able to suggest good background material for you.

NAME OF STUDENT: _____

DATE DUE: _____ PERIOD: _____

WORKSHEET ON MOTION WITH CONSTANT SPEED

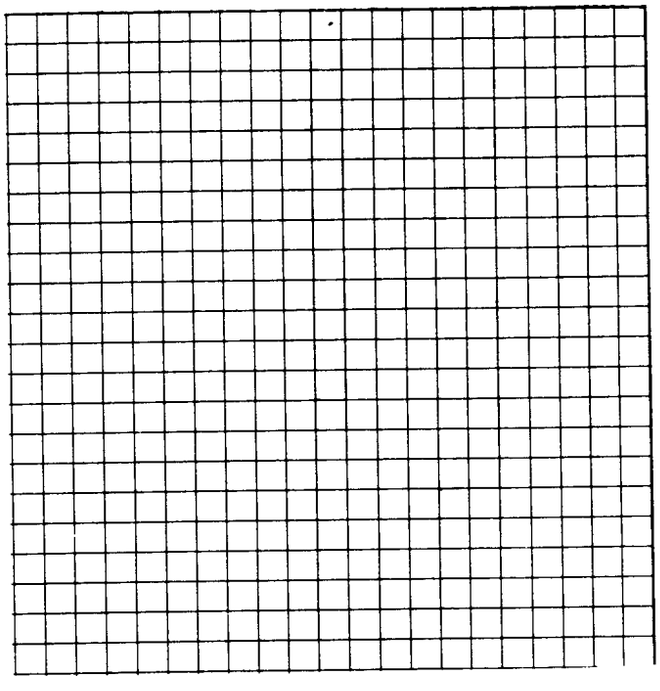
INITIAL: A FINAL: B



1. The marks on the board sketched above show where the front of a moving cart was at t = 0, 1, 2, 3, 4, and 5 seconds. The total distance from A (t = 0) to B (t = 5 seconds) is 75 cm. Describe how you could use the board and the blackboard to make a graph showing the relationship between position and time for the motion of the cart.

2. Using the graph outline on the right (i.e. GRAPH I) make a graph of the position of the cart versus time. Label the axes with the quantity being plotted and the unit of measurement. Put appropriate scales on the axes for time and position.

GRAPH I



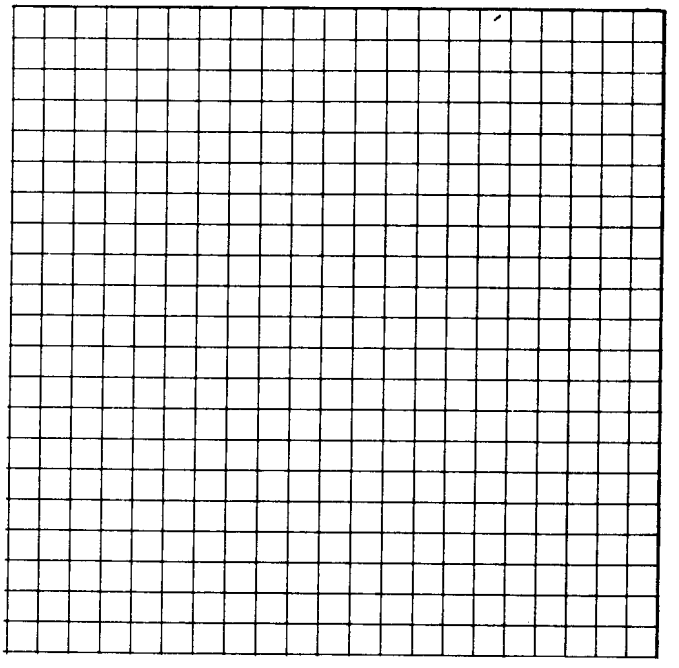
3. In this experiment, how do the marks on the board show that the cart's speed is nearly constant?

4. What is constant about graph I in question 2? Name and define this quantity.

5. State the relationship between the constants of questions 3 and 4 in algebraic symbols. Find the value of the speed. (Be sure to include the units as well as the numbers for the rise and the run.)

6. Using the graph outline on the right (i.e. GRAPH II) make a graph of the speed v of the cart versus time. Label the axes with the quantity being plotted and the unit of measurement. Put appropriate scales on the axes for speed and time. (NOTE: v is the usual symbol for speed.)

GRAPH II



7. From t = 5 seconds on the time axis, draw a vertical line upward until it intersects the graph. What is the shape of the area enclosed by this line and the axes.

8. The enclosed area of question 7 has a base t and height v. What does its area represent? (Be sure to include the units as part of the measurement and the calculation.) Does your answer check with what you know about the motion from the experiment?

9. Does the "area under the graph" concept work for finding the distance traveled between t = 2 and t = 4 seconds? What adjustment did you need to make?

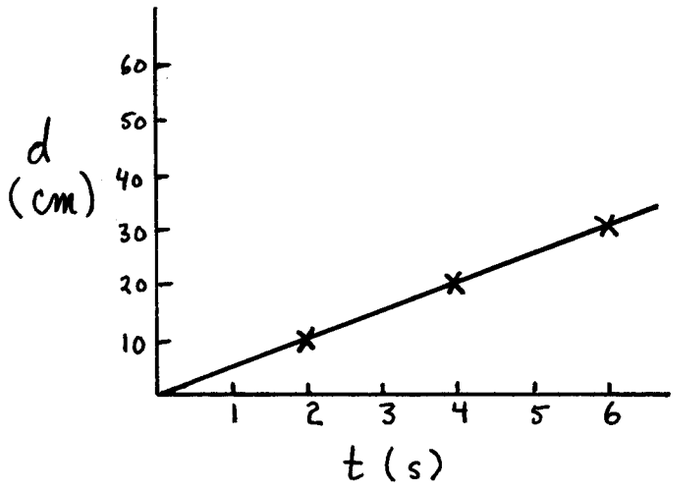
10. Using the area under the graph concept, write an equation in algebraic symbols expressing the relationship between v, Δt, and Δd. Then compare this equation with the one you wrote in question 5 using the slope concept.

IMPORTANT IDEA

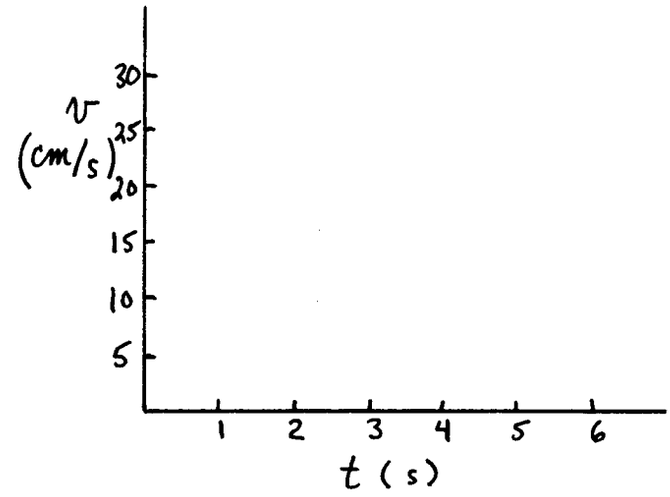
An important point to be learned is that Graph 2 can be completely derived from Graph 1 (by finding the slope of Graph 1); and conversely, Graph 1 can be derived from Graph 2 alone (by finding areas under the Graph 2 at successive time intervals and knowing the initial position of the moving object). Both graphs contain exactly the same information, and so do the two equations noted in questions 5 and 10. You'll find that these ideas work for any motion even when the speed is not constant and the distance-time graph isn't a straight line.

11. The first motion is described on GRAPH IIIA below. Plot the same motion on the blank v versus t graph outline IIIB.

GRAPH IIIA

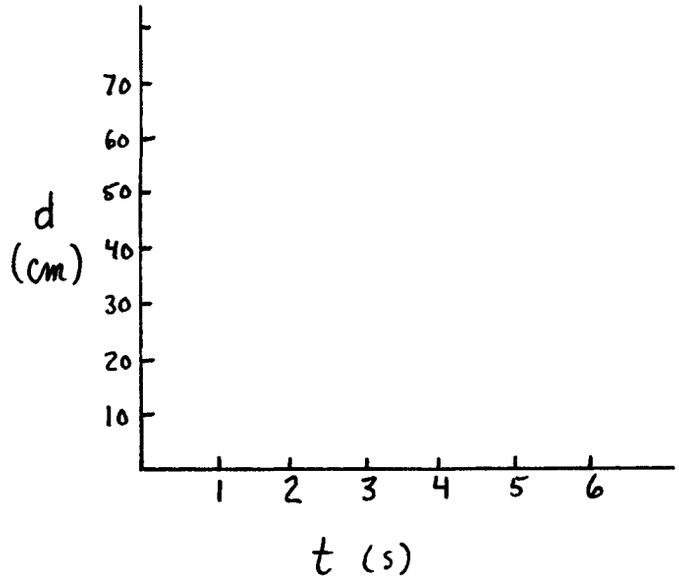


GRAPH IIIB

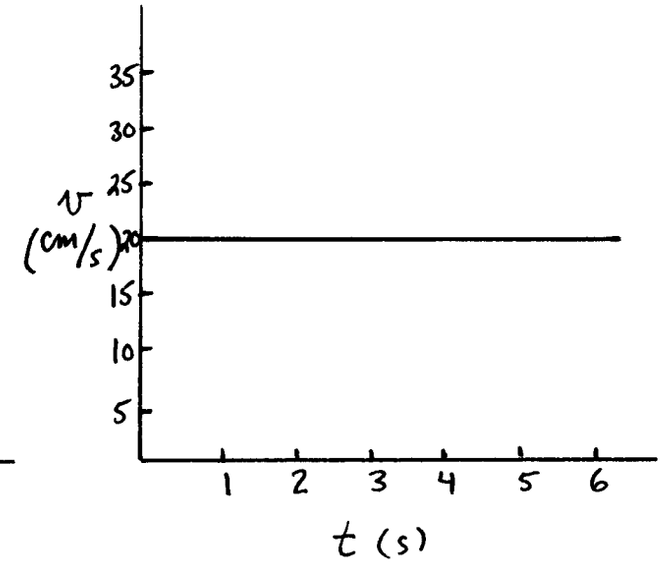


12. Another motion is described on Graph IVB below. Plot the same motion on the blank d versus t graph outline IVA.

GRAPH IVA



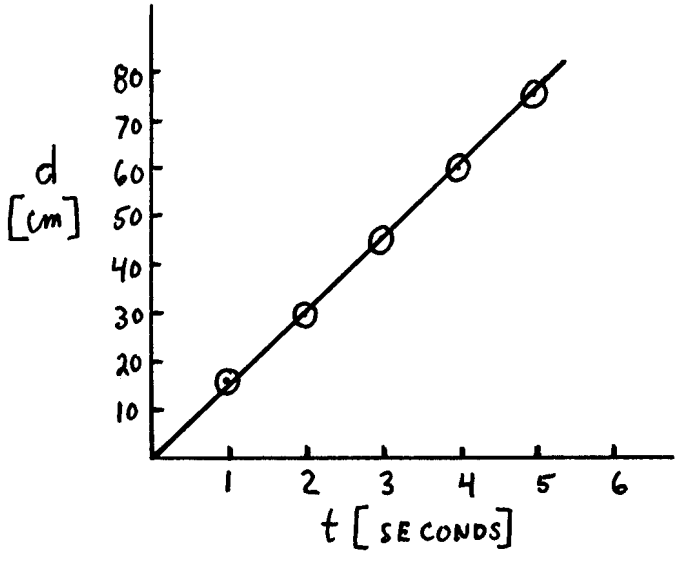
GRAPH IVB



KEY FOR WORKSHEET ON MOTION WITH CONSTANT SPEED

1. Use the marked board as a ruler to draw axes on the blackboard. Mark the distances on the vertical axis and make 5 equal time divisions on the horizontal axis. Plot the points that correspond to each position versus time pair.

2. GRAPH I

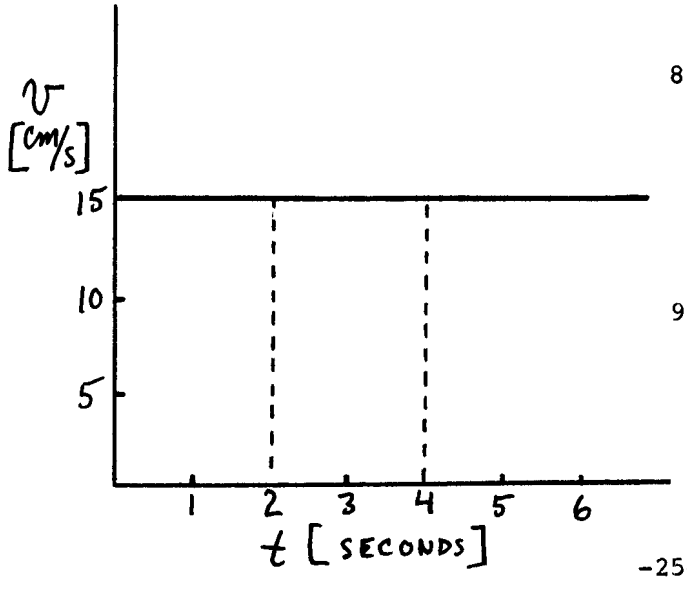


3. The marked board shows that the distances traveled in equal times were very nearly equal.

4. The slope of the graph is constant. Slope = rise/run = $\Delta d / \Delta t$.

5. In words: constant slope represents constant speed. In algebra: $V = \Delta d / \Delta t$.
Calculation: v = 75 cm/5 seconds = 15 cm/second.

6. GRAPH II



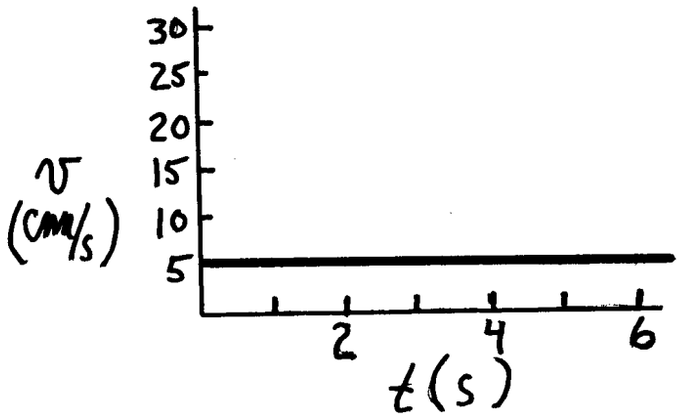
7. The enclosed shape is a rectangle.

8. Area = vt = 15 cm/second x 5 seconds = 75 cm. This agrees with the experiment in which the cylinder rolled 75 cm in 5 seconds.

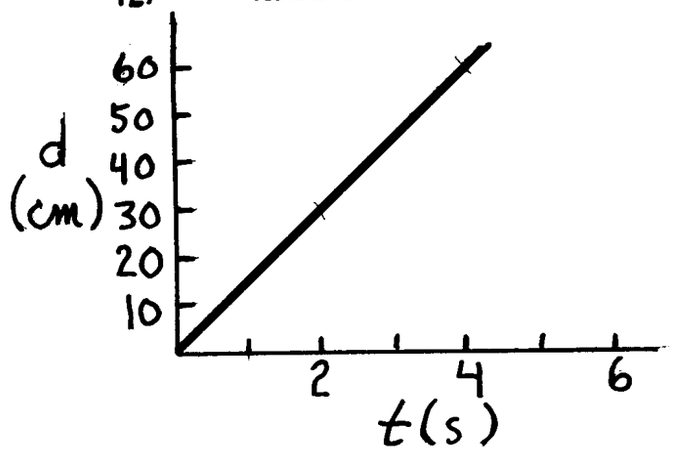
9. Add vertical lines at t = 2 seconds and 4 seconds and find the area enclosed: Δd = 15 cm/second x (4-2)seconds = 30 cm

10. From question 10 $\Delta d = v \Delta t$. From question 5, $v = \Delta d / \Delta t$. It's the same equation, just rearranged.

11. GRAPH IIIB



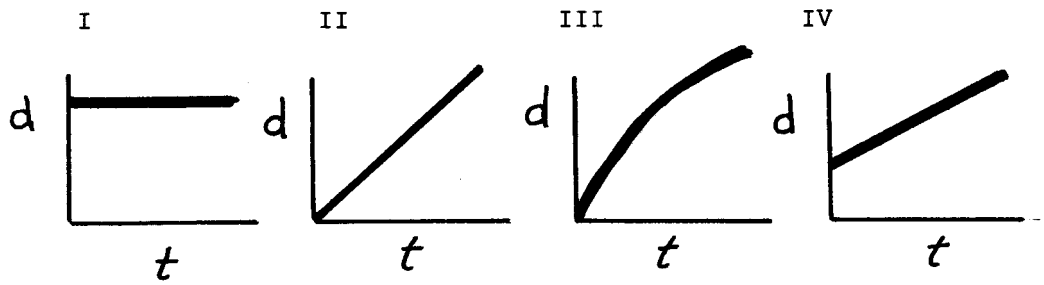
12. GRAPH IVA



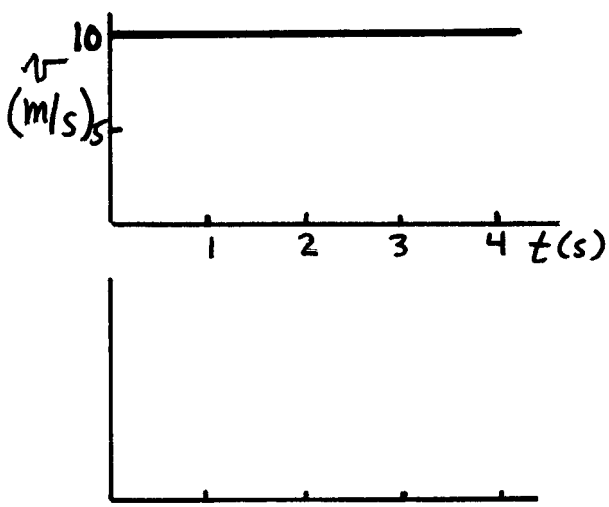
QUIZ ON CONSTANT SPEED NAME OF STUDENT: _____

DATE_____ PERIOD: _____

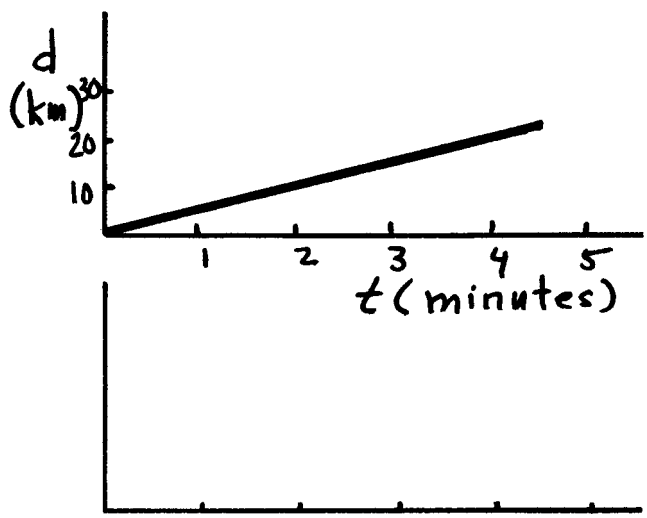
1. Which of the following graphs are consistent with a body traveling at constant speed?



2. Plot the position versus time graph that corresponds to the speed versus time graph below:



3. Plot the speed versus time graph that corresponds to the position versus time graph below:

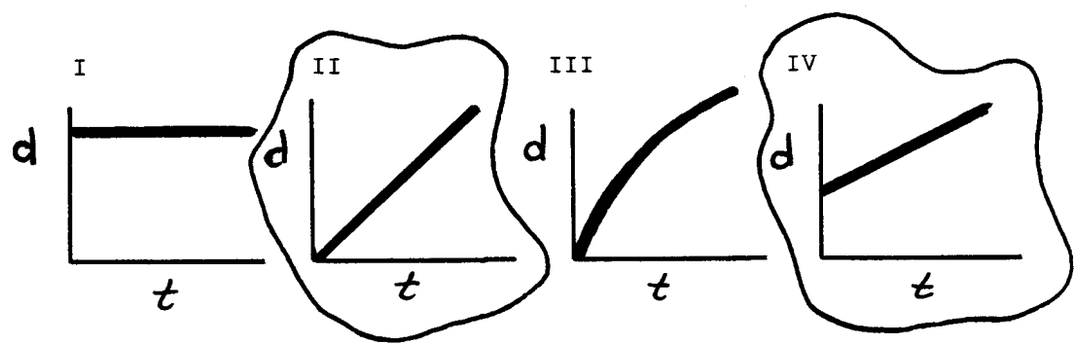


4. As far as we know, nothing can travel in free space as fast or faster than light does. The constant speed of light in space (rounded off to three significant figures) is 3.00×10^8 meters/second. One of the first experiments to be conducted when the first human landed on the moon was to time a beam of light reflected from the moon. It takes 2.50 seconds for a laser beam to leave earth, reflect from the moon, and return to earth. Use this information, to find the distance from the earth to the moon.

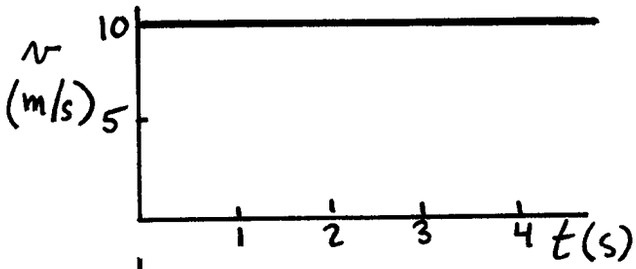
QUIZ ON CONSTANT SPEED NAME OF STUDENT: [ANSWER KEY]

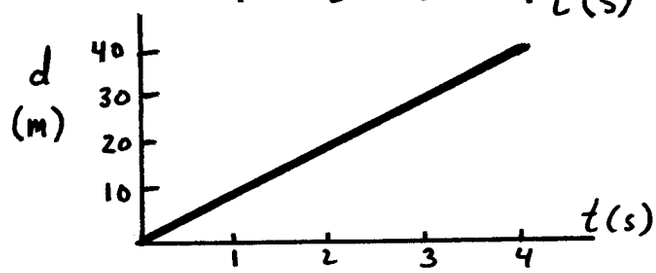
DATE_____ PERIOD: _____

1. Which of the following graphs are consistent with a body traveling at constant speed?

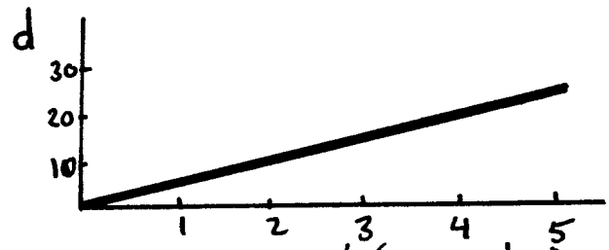


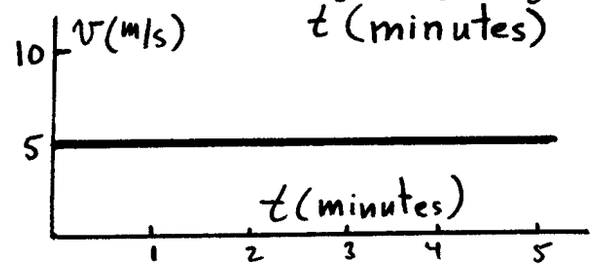
2. Plot the position versus time graph that corresponds to the speed versus time graph below:





3. Plot the speed versus time graph that corresponds to the position versus time graph below:





4. As far as we know, nothing can travel in free space as fast or faster than light does. The constant speed of light in space (rounded off to three significant figures) is 3.00×10^8 meters/second. One of the first experiments to be conducted when the first human landed on the moon was to time a beam of light reflected from the moon. It takes 2.50 seconds for a laser beam to leave earth, reflect from the moon, and return to earth. Use this information, to find the distance from the earth to the moon.

ADDITIONAL IDEAS TO HELP YOU GET STARTED

Body Units

Parts of the body can serve as models for various metric units. For instance, the width of the fingernail on your little finger is about 1 cm; from your chin to the tip of an outstretched hand is approximately 1 meter; and a six and a half foot basketball player is about two meters tall.

Constant speed

This is not as common in real life as you might think. If you have an air track or hockey table that is level, a glider will float from one end to the other without perceptibly slowing down. A wind up or a battery operated toy tractor or bulldozer will maintain nearly constant speed. In the first case, the absence of friction is important, while in the second case, friction is essential; without friction wheels would just spin.

A walking student could take the place of the rolling cylinder in the constant speed experiment described previously. A course can be laid out in a hall or outside the classroom, and while each student walks through the course other students mark the distances walked in equal time intervals (or, alternatively, measure the time taken to walk equal distances). A description of such an experiment is found in the September 1983 issue of The Physics Teacher magazine. The article is called "Kinematics of a student." A reprint of the article is in the supplementary materials included with this kit.

Average speed

The slow bicycle race described in the Physics Olympics Events (described in an AAPT booklet) is a lot of fun for students to do, and would be a good example of how a varing speed is "smoothed out" into a "constant" average speed.

III. THE LABORATORY

I hear and I forget.
I see and I remember.
I do and I understand.
-- Chinese proverb

Physics has to do with the behavior of real things, and a direct personal encounter with reality is an essential characteristic of a good physics course. If you wanted to teach an understanding of football, you wouldn't confine your students to a rule book. Seeing the game played is helpful, but the best understanding comes from playing the game.

Similarly, your textbook spells out the rules of physics. But it's important that students experience physics in action by watching demonstrations, and best of all learn by doing physics in the laboratory.

One aspect of a laboratory activity that is not always appreciated is what happens when things take an unexpected turn. This can be exasperating, and there is a temptation to fix matters so that the activity "comes out right." Don't do it! Making mistakes or finding unexpected results can provide one of the most instructive opportunities when working in the laboratory. Students may well learn more from the experience by searching out and correcting their own mistakes, and by questioning their assumptions when results are not what they expected, than by following such a carefully prepared set of procedures that no wrong turns can be taken. If fact many teachers design laboratory activity which require students to solve problems that arise.

A. Basic Consideration

1. If you are taking over a physics course that has been taught recently, you should probably adopt the laboratory manual used by your predecessor. This makes it likely that your storeroom contains the apparatus you'll need. You can also choose to use the laboratory manual associated with your textbook. You will also find some simple, introductory activities outlined in this kit that you could use as starters.

2. It's always best to keep the laboratory activities in step with topics being discussed in class. The laboratory should not be run as a separate course, as it is done in some college courses. If your text starts with kinematics (i.e. the description of motion) then the first laboratory activity should present a situation in which the speed and/or acceleration of an object are studied.

3. In many cases it is best to introduce a new topic to students with a laboratory activity before assigning textbook reading or lecturing about the topic. When this is done the discussion, reading, and analysis that follow will be based on concrete experiences. But what if you have one double period a week, ostensibly for doing laboratory activities? If you're serious about trying to introducing new concepts in the laboratory, you often won't be able to wait until "laboratory day." Many teachers schedule laboratory activities during regular class time, perhaps on successive days. However, due to limited time or materials this is just not possible at all times. The next best alternate is to substitute a demonstration in place of the laboratory activity.

4. You really should do each laboratory activity yourself to make sure that the directions are clear, the equipment works properly, the time allotted for the activity is realistic, and to identify possible pitfalls. If this is not always possible, do a few laboratory activies each year so that you will gradually be able to improve the laboratory activies.

B. The Apparatus

1. Identifying the apparatus that you'll need for a particular laboratory activity is a first step. Many laboratory manuals list apparatus by name and show drawings of it in use. See the appendix for an essay called "Equipment -- or What is That Thing in My Storeroom?"

2. How many complete sets of apparatus do you have? This is an important consideration because it will determine the number of students in a laboratory group and the size of the group. The optimum size group is two. If three or more students work together in the laboratory, one or more will usually be left out. If a student works alone, there is no interaction as the activity is completed. We deal with this more specifically in item 4. under "The Laboratory Period" below.

3. If the laboratory room is separate from the classroom, it is best to have the apparatus at the laboratory tables before the laboratory period begins, and it should be checked to make sure that it is working properly.

C. The Laboratory Period

1. Discipline during a laboratory activity is not the same as it is during class! Students must have some freedom to talk and move about. But discipline must be clearly defined. The thing to be avoided and quickly checked is the kind of fooling around that students can fall into when their attention strays. This behavior is not only distracting, but dangerous. Be available to your students as a consultant, and use the informal atmosphere of laboratory time to get to know your students. The success of your students will be enhanced by your questions, proddings, and exchanges.

2. In the laboratory you are directly responsible for safety. You must be aware at all times of what's going on. While students are working in the laboratory, don't mark papers et cetera. A teacher who leaves the laboratory unproctored, for any reason, is in a very shaky legal position if there should be an accident.

3. Before sending students to laboratory stations it is usually best to introduce the activity to the class. This doesn't mean that you should do it so that students can copy your technique, but you do need to make the purpose of the activity clear, display the apparatus, warn about hazards to apparatus and/or experimenter, and motivate students by asking and inviting questions.

4. For most laboratory activities students seldom work alone. Teams of two or three are usual; larger groups are rarely effective. Students can organize themselves as they wish, choosing partners in any natural way. However, you may find that two girls make a better laboratory combination than a girl and a boy. All too often the girl takes notes while her partner does the laboratory activity. Be on the watch for any partnership in which one member is doing all the work, by choice or by default. You may have to help the loners get together. Keep grouping as flexible as the amount of available apparatus allows. Some teachers have students change partners on different laboratory activities.

D. The Laboratory Report

1. Many teachers avoid the individual formal laboratory report for every laboratory activity. This is the kind of report that you may remember from your own school days. Although it may be desirable to do a few reports in a formal manner, it is not likely that you or your students will have the time to do this for every laboratory activity. As described below there are a number of alternatives. Whatever the reporting method, the major value to students lies in the three step process of:

I. MAKING MEASUREMENTS AND OBSERVATIONS
II. ANALYSIS OF THE INFORMATION OBTAINED IN I
III. DRAWING CONCLUSIONS BASED ON THE ANALYSIS IN II

A student's laboratory notebook should be clear enough so that you and/or the student can later understand the observations, analysis and conclusions. Insist that writing and spelling used in any report be clear and correct. You don't have to put up with sloppy science or sloppy English. Scientists like almost everyone else must know how to communicate their work to others.

2. One laboratory report plan requires each student to keep a laboratory notebook. A good format can be maintained in a spiral bound notebook with alternate pages of graph paper and lined paper for writing. If you are following a published manual there is no need to repeat in the notebook the list and drawings of apparatus, or the details of the procedure that appear in the manual. The notebook is used to record observations, data, and calculations; draw graphs; describe calculations; describe idiosyncracies in the data or unusual occurrences; answer questions posed by the teacher; assess accuracy of results and/or errors; and above all make a summary statement about the outcome of the activity. Students should bring these notebooks to every class meeting and hand them in periodically to be checked.

3. Some teachers use a scheme in which each group of students hands in a single report. The groupings are permanent, with each student having a specific role for the report (e.g. record data, draw graphs, do error analysis, write formal report, et cetera) responsibilities rotate within the group. All students in a group receive the same grade for the report.

4. Another plan asks students to produce simple, informal individual reports in time for a post-laboratory class discussion. This discussion will be much more meaningful if students have already analyzed their data and come to at least tentative conclusions.

5. Of course, if your laboratory manual is of the workbook variety with blank data tables and fill-in-the-blank questions, your chore is easier; however, students ofter feel that the idea is to fill the blanks rather than learn physics, and many teachers object to the shallowness of the laboratory work that results from using this type of manual. When you have more experience, however, you may prefer a less cut-and-dried approach.

E. Follow-up of Laboratory Activities

In the class period following a laboratory period, it is worthwhile to discuss the laboratory activity. What kinds of graphs or numerical values have evolved from the data, and how do you account for the usual disagreements and discrepancies? Ask students to discuss their ideas related to the laboratory activity. Unless carelessly generated or recorded, the data are right, given the particular conditions under which the measurements were made.

A useful technique to help arrive at a reasonable conclusion from many sets of data is to compute an average for the whole class. This works well if the laboratory activity is to determine the value of some well-known constant such as the acceleration due to gravity or the index of refraction of water.

A great deal of sound teaching and learning can be accomplished by considering "How do you know..." and "What if...." kinds of questions. In this way the class moves smoothly from the experimental details to the physical concepts.

F. Safety in the Laboratory

Laboratory safety is often a matter of common sense and alertness. It is not too different from raising your own children. Just as you don't allow a child to run across a busy highway, a teacher will tell a student with flowing hair to tie it back working with a bunsen burner or power machinery.

While some hazards are obvious (a student's foot can be injured by a falling mass), others may be less easily recognized. In the early part of most physics courses, when you are teaching kinematics and dynamics, the dangers are mostly of the obvious type. The points that follow concern later parts of the course, although if you have any students working independently, you may need to know about them earlier.

1. The 120-volt power line is potentially lethal. Students should never be allowed to work with exposed uninsulated power line wiring. On the other hand, no one was ever hurt by touching the terminals of one dry cell. The output terminals of commercial low voltage power

supplies (less than 25 volts) which you may find in your storeroom, or possibly at each laboratory station are also perfectly safe electrically. But sometimes wires carrying a heavy current from one of these sources can get hot enough to give a painful burn.

2. Discharges from induction coils. Tesla coils, and Van de Graaff generators will give an unpleasant shock, but are usually not dangerous.

3. Lasers designed for educational use are not powerful enough for the beam to be a real danger. Nevertheless, the beam should not be allowed to enter a student's eye either directly or from mirror-like reflections.
   Vapor lamps bright enough to make you squint should also not be viewed directly. Mercury vapor lamps should have an ultra violet filter.

4. We don't handle chemicals very much in physics, but there are two which used to be used: mercury and carbon tetrachloride. Don't use either one. Broken thermometers leading to mercury spills should be cleaned up by the teacher. See your chemistry teacher for help.

5. State laws vary widely on laboratory safety. You should obtain a copy of your local and/or state safety regulations. The administrator who is your immediate superior should be able to tell you more about this.

6. There is an AAPT publication giving details about safety in the physics laboratory: "Teaching Physics Safely: Some Practical Guidelines", by R.W. Peterson. To order this book, see the AAPT products catalog in the supplementary materials.

7. If there are clear safety problems in your classroom or laboratory that are not addressed by school administrators, put the problem in writing so that the record shows you are aware and concerned.

Keep for reference

HOW TO DRAW AND INTERPRET GRAPHS

Graphs are used to show how one quantity depends on another quantity (e.g. distance traveled depends on time of travel). Since discovering and understanding relationships between measured quantities is one of the main activities of physics, making and using graphs is important in many laboratory activities. A graph should be thought of as a capsule summary of the data for a laboratory activity, and the graphs should be intelligible without any auxiliary description.

1. Plan the axes

Usually it is clear in a laboratory activity that one of the quantities being measured depends on the other. For instance, when a ball rolls down an incline its speed at any instant depends on the time since it was released. In this case, the speed is considered the dependent variable, and the time is the independent variable. It is customary to plot the dependent variable (in this case the speed) on the vertical or Y-axis, and the independent variable (in this case time) on the horizontal or X-axis.

A graph should be easy to read. Thus, a single square of your graph paper can stand for one, two, five, ten, one-half, two tenth, or one-tenth of a unit, but never for a difficult-to-read value like seven or one-third. Don't try to number every line along the axis. You need to provide enough divisions on the axis to make the graph easy to read without being cluttered. It's not necessary to use the same scale on both axes: after all, they often represent different quantities. Try to choose scales so that the whole graph will fill the page.

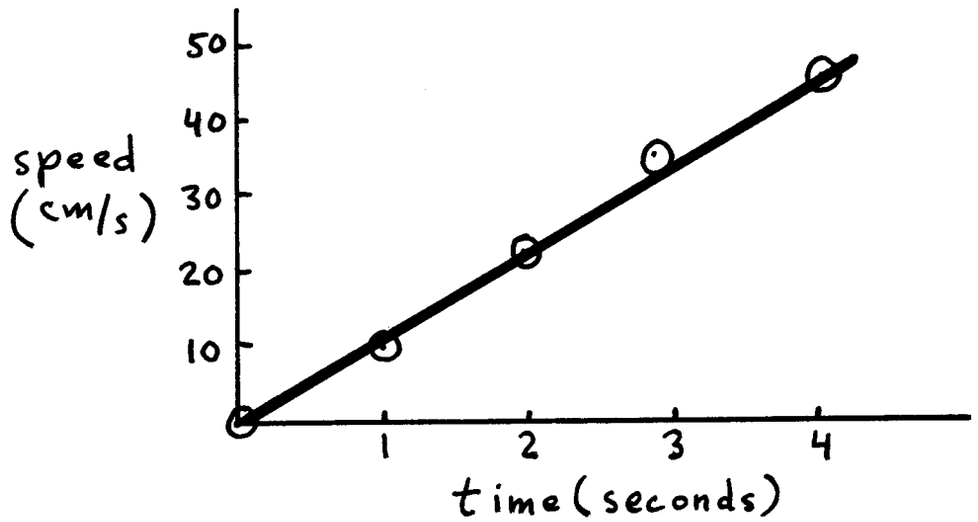
Label each axis with the name of the quantity being plotted, and the units in which it is expressed (e. g. speed in [meters/second]). A title (e.g. "Speed versus Time for Falling Object") should be placed at the top of the graph paper.

2. Plot the points

Each point on a graph represents a pair of measured values. Locate each point on the graph as exactly as you can, and mark it using a small but clear dot. Make a circle around each dot so it can easily be spotted. The size of the circle should represent the approximate uncertainity of the measurements. Some people use little +'s for the points. In more advanced work it is customary to show the probable uncertainty in each quantity by the size of the arms of a cross drawn through the data point.

3. Draw the line

For many laboratory activities the graphed points will suggest a straight line or a smooth curve, often beginning at the origin. Due to uncertainty of measurement, there is bound to be some random scattering of the points. If the actual relationship is not apparent, additional measurements may be needed.

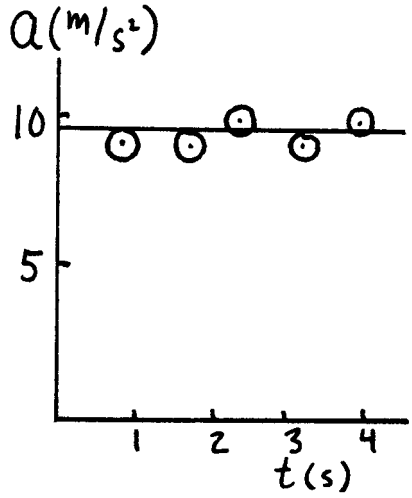


If you think the data represents a straight line graph, use a ruler to draw a straight line, locating it with about as many points scattered above the ruled line as below it. The circles drawn around the data points will prevent the data points from being lost when you draw the graph. If a single point seems to be quite far from the line suggested by the other points, try to return to the laboratory to chech the values. If you cannot check it, leave it on the graph but ignore it when drawing the line.

If the points indicate a curve, draw it smoothly, passing close to as many points as possible. Don't draw a series of broken point-to-point lines. In elementary physics laboratory activities, the curved graphs are generally, simple sweeps which are concave upwards or downwards.

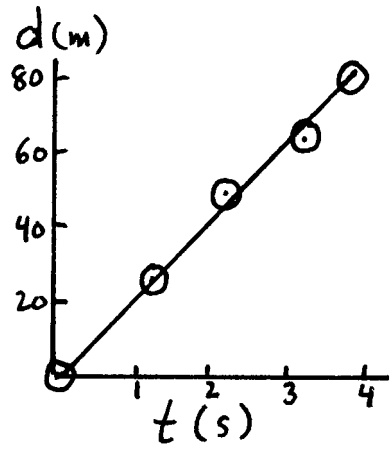
4. Translating graphs into English and algebra

What can the shape of a graph tell you about the possible relationship between the dependent variable (we'll call it Y) and the independent variable (call it X)? Here are some examples you will encounter in your physics course.



a. Straight line parallel to the X-axis

English: The Y value is constant for all values of X.
Algebra: Y = k, where k is a constant
Example: $a_g = 9.8\ m/s^2$. The acceleration due to gravity for a body falling in a given location has a constant value. (Experimental values will vary randomly about an average, as shown at the left.)

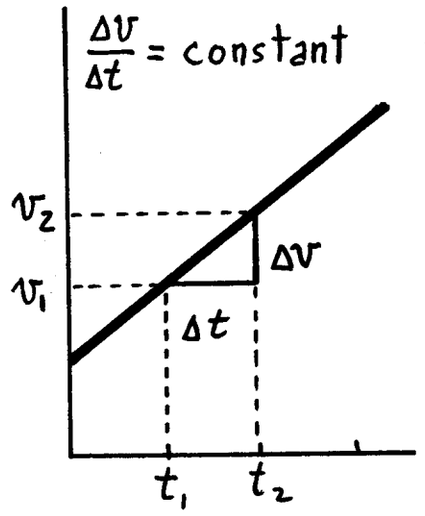


b. Sloping straight line through the origin

English: The quantity plotted on the Y axis is directly proportional to quanity plotted on the X axis. Note that in this relationship whenever X doubles, Y also doubles; and when X triples, so does Y.
Algebra: Y/X = k, or Y = kX
Example: d = vt. For an object moving with a constant speed v, the distance it travels is directly proportional to the time the object has been traveling. In this case k is represented by v.

At times you can extend a graph back to the origin without making a measurement. In the speed versus time example, one can argue: "Since the ball was released from rest, when time is zero the speed is zero."

c. Sloping straight line not through the origin



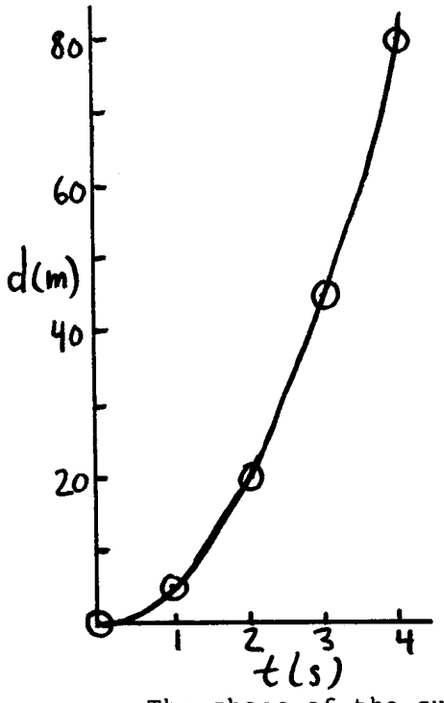
English: the slope of the line is constant (as for case b), therefore the change in Y is directly proportional to the corresponding change in X.

Algebra: $\Delta Y / \Delta X = k$,

or $(Y_2 - Y_1)/(X_2 - X_1) = k$

Example: $\Delta v / \Delta t = a$ (when acceleration is constant and the initial speed is arbitrary). Rewriting, $(v_2 - v_1)/t = a$, or $v_2 = v_1 + at$. (This assumes initial speed is zero, thus $\Delta t = t_2 - 0 = t$). This equation may remind students of the slope intercept equation $Y = mX + b$, from algebra. Students should also be reminded that if k (or m) is negative, the line will slant downward instead of upward.

d. An upwardly-concave smooth curve through origin



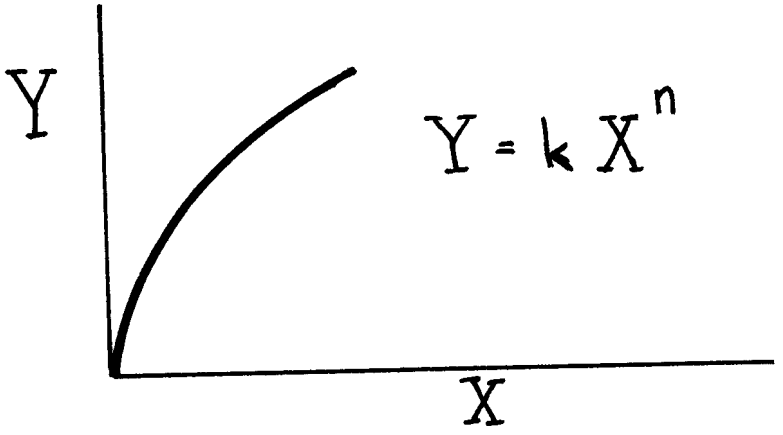
English (in the case illustrated at the right): The Y quantity is directly proportional to the square of X. Note that if the point X = 0 and Y = 0 is included, when X doubles, Y becomes 2 squared or 4 times bigger; when X is multiplied by 3, Y is multiplied by 3^2, et cetera.

Example: $d = kt^2 = (1/2)at^2$ when the acceleration is constant. Distance traveled is directly proportional to the square of the elapsed time.

The shape of the curve in (d) usually represents the relationship $Y = kX^n$, where n is any exponent greater than one. In elementary physics n is most commonly 2, but could also be 3 or 3/2.

Graphs which curves like (e) (see next page) are often represented by $Y = kX^n$, where n is between 0 and 1 (i.e. 1/2. Example: $T = k\sqrt{\text{length}}$ The period T of a pendulum is directly proportional to the square root of its length l. When l is doubled, T is multiplied by the square root of 2.

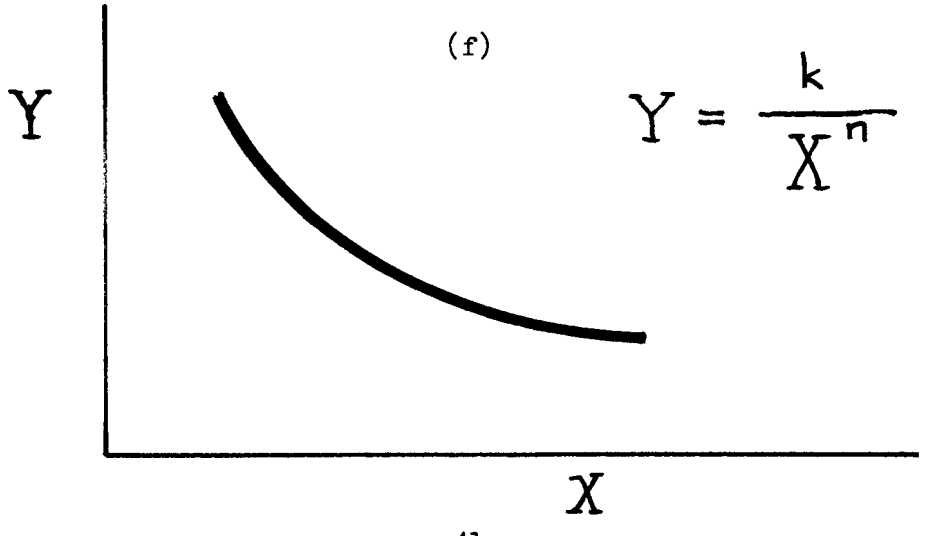
(e)



A graph curving downward as in (f) often indicates an inverse proportionality: $Y = kX^{-n}$, or $Y = k/X^n$, where n can be anything but is usually 1 or 2. Example: $F = k/r^2$. The gravitational attraction between two masses is inversely proportional to the square of the distance r between them. When r doubles, the attraction F drops by factor 1/4; if r is cut in half, F becomes 4 times larger.

Algebraically, all of the graphs described are of the form $Y = kX^n$, where n can be positive, negative, or zero, and where k will have the required value and units to relate Y to X.

(f)



IV. MOTION IN A STRAIGHT LINE

A. Overview

Straight line kinematics includes a number of concepts that seem rather direct; however, they may be confusing to students. The trouble comes when students intuitive ideas about speed and acceleration need to be precisely defined. Students find to their dismay that they must discriminate between constant speed; initial speed; final speed; average speed; and instantaneous speed, and that their intuition is often wrong, (e.g. Most students' intuition tells them that zero speed always implies zero acceleration.)

In addition, students must learn to interpret the definitions of terms relating to distance, speed, and acceleration in three related languages: words, graphical display, and algebra -- all equally important to real understanding. Concepts often get mixed up, while algebraic expressions accumulate relentlessly. No wonder students get confused!

Thus you should allow students the time, hands-on experience, practice, and repeated testing it takes to master new skills. They (and you, too) may find it comforting to know that understanding slope and area concepts covered in kinematics are useful not only in physics, but also in concurrent or later mathematics courses and in many post high school courses.

Throughout this section you'll find student worksheets and quizzes, reference sheets, and suggestions for other learning aids relating to straight line kinematics.

B. An Experimental Introduction

In section II, it was suggested that you and your students conduct a classroom experiment with a cylinder rolling along a flat surface at constant speed. Students could then analyze their data by converting it into graphical form -- first on the blackboard, then on graph paper, and finally from graphs into words as well as algebra. The next logical step is to have students record successive positions of something moving at a changing speed. How they do this depends on what kind of recording and timing equipment you've found in your storeroom.

If you didn't find anything at all, it is perfectly possible to continue the same style of operation as before, but on a tilted board to get acceleration, and with the class divided into groups to take their own data. Other suggestions for an acceleration experiment for limited equipment can be found in this kit. As a last resort you could use strobe photographs, found in many textbooks or laboratory manuals.

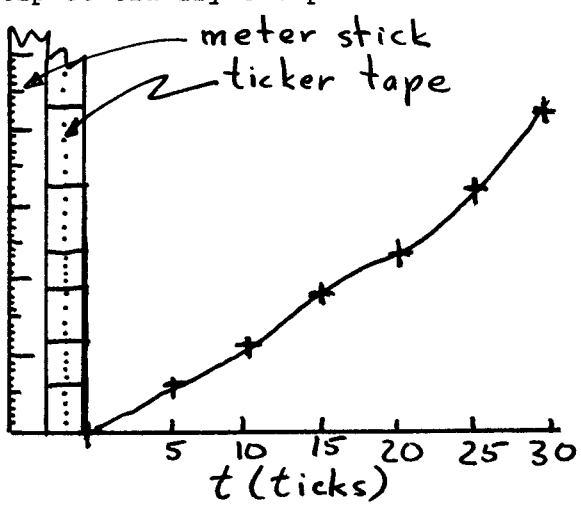
However, you may find some recording timers in your storeroom. These are small, simple devices which print dots on ticker tape at equal time intervals as the tape is pulled through them. This is analogous to marking the rolling cylinder positions on the board every second or so, except that the time intervals for the recording timers may be as small as 1/60 second.

As you can tell by the standard electrical cord attached to them, some timers plug directly into regular electric outlets. Other types will require low voltage dry cells (often called batteries) to run them. If you have this later kind of timers, look for dry cells (they may have gone dead over the summer!), or Direct Current (D.C.) power supply). These power supplies are like car battery chargers. They plug into normal receptacles and turn high voltage alternating current into safe, low voltage direct current at their output terminals. That's where you hook up the timers, using strands of insulated wire. Many schools will have a source of low voltage D.C. at the student laboratory benchs. You'll also need C-clamps to fasten the timers firmly to the tables, carbon discs to make the dots print, and rolls of ticker tape.

Unless you are following the instructions of a laboratory manual, we suggest that you clamp half the timers to table tops so the tape pulls through horizontally. The other half can be mounted on chair backs, cupboard doors, or any upright support so that a weighted tape can drop through the timer with as little friction as possible. Show the students how the timer works, and then give them two tapes apiece (about 50 cm long) with instructions to record one horizontal and one vertical motion. The horizontal motion is more interesting if the tape is pulled through the timer with a speed that is irregularly fast and slow. The vertical motion is made by the falling object. Making tapes doesn't take long, so students will soon be ready to examine their own handiwork.

As students look at the irregular motion, ask them how they can tell when the tape shows the speed was (a) increasing; (b) decreasing; (c) constant; (d) maximum. You'll find intuition stands students in good stead thus far. Also, if each student has a ruler, they will have little difficulty determining the value of the maximum speed in cm/tick. A tick is an arbitrary unit of time and is the time interval that passed between creation of the dots. (It's not important to know the exact relation between ticks and seconds.)

Students will readily agree that increasing speed implies a positive acceleration, and decreasing speed implies a deceleration. Note that deceleration can just as well be called negative acceleration. But when you ask students to tell when the acceleration had its maximum positive or negative value, very few will be able to do so by looking at the tape. At this point, suggest that a graphical analysis of the data on the tape will help to clarify the problem.



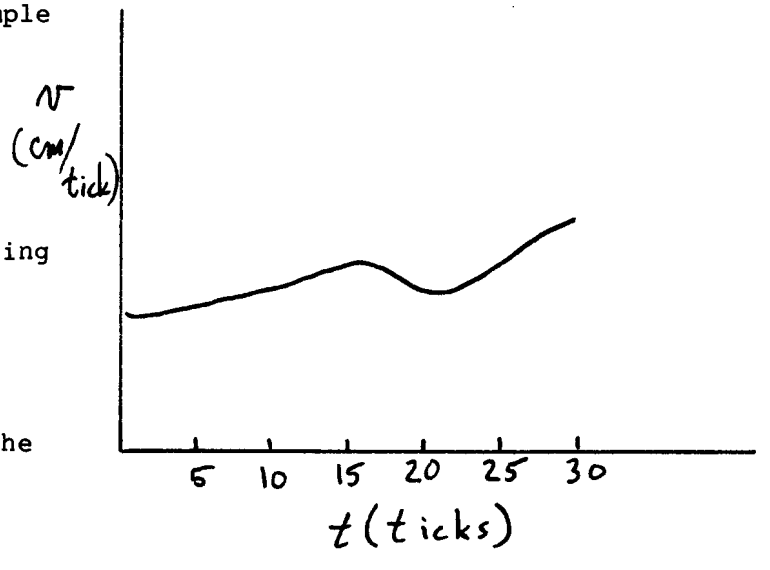
If any students suggest using the tape itself as the position axis as they did with the marked board, invite them to carry out their ideas on the blackboard. Fastening the tape to a meter stick makes drawing the vertical axis and measuring distances easier. See diagram on the left. The horizontal time axis can then be

marked off in convenient units of five or more ticks. In order to make a graph that fits on a piece of paper, the students will realize that the vertical axis will need to be scaled down. Each student in class should make a graph of the data on their ticker tape.

After the position versus time graph is drawn with a smooth curve through the plotted points, it's important for students to appreciate that they can get the same qualitative information about the speed by looking at the graph as they could from looking at the tape. The same information is present but in a different form. Now it is the slope rather than the dot spacing that visually signals the value of the speed. Where the slope is steepest, there the speed is a maximum. Where the slope is most nearly horizontal, the speed is smallest. And in between, where the slope is becoming either more or less steep, there is positive or negative acceleration.

To demonstrate how the slope changes from point to point, slowly move a ruler along the curve. While doing this be careful to keep the ruler tangent to the curve. The slope of the ruler reprsents the speed. Then ask the class what a rough sketch of the speed versus time graph would look like? Does it have one or more peak values, and if so, during which time intervals? Is it ever zero or very small or constant? What is happening between peaks and valleys? Ask students to deduce the shape of the speed versus time graph. Perhaps you can get an argument going as to whose sketch is most reasonable. Put a good one on the board near the position versus time graph.

A rough sketch of the speed versus time graph corresponding to the sample position versus time graph on the previous page looks like this.



Emphasize that the speed versus time graph is a record of the changing slope of the position versus time graph. Can they guess what the changing slope of the speed versus time graph indicates? It must be the acceleration. Where speed is increasing, the upward slope is positive and so is the acceleration.

You can use a ruler with a speed graph to show acceleration just as you used the ruler to demonstrate speed on a position graph. When the speed decreases, the downward slope of the ruler signals a negative acceleration. Where the ruler is parallel to the horizontal axis, the acceleration is zero. This occurs when the speed is constant (as between D and E in the sketch on the last page), but it also occurs momentarily when the acceleration is changing from positive to negative, as at A and C, or changing from negative to positive, as at B.

Another way to say this is "whenever a speed stops increasing and begins to decrease, or vice versa, the acceleration must be zero at that instant." But beware! Students are prone to say that at the instant when a body thrown upward reaches the top of its trajectory, its acceleration is zero as well as its speed -- wrong! In this case, direction as well as speed is changing, and that makes a difference, as we'll discuss later.

Turn next to the falling body tape and ask students to compare it with their horizontal tape. In most cases they'll observe that the dot spacing seems to increase in a much more regular way until the object hits the floor. When the object hits the floor there is an abrupt change in the pattern of dots. With this tape students can begin to make quantitative measurements. Each student should make a position versus time graph for his or her own falling body tape. The data sheet below is useful for recording kinematic data. On the next page, there is a three page worksheet on "ANALYSIS OF A FALLING BODY TAPE." The instructions are self-explanatory, and the second and third sheets carry students forward into speed and acceleration calculations.

NAME OF STUDENT: _____

DATE: _____ PERIOD: _____

WORSKHEET ANALYSIS OF A FALLING BODY TAPE

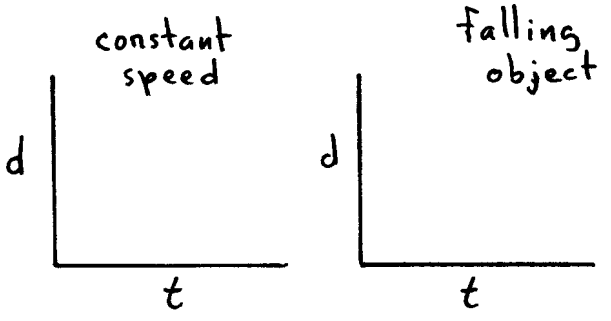
1. About how many ticks are there on your tape from the first one you can count to the last before the object hits the floor?

2. Divide the tape up into at least six equal time intervals -- more if you have enough dots before the crash. Each space between dots represents 1 tick. How long is your Δt in terms of ticks?

3. Measure the total distance from the first dot to each successive dot, filling in the data table as you go. Then draw the position versus time graph. (If you need to, review the reference sheets on good graphing techniques.)

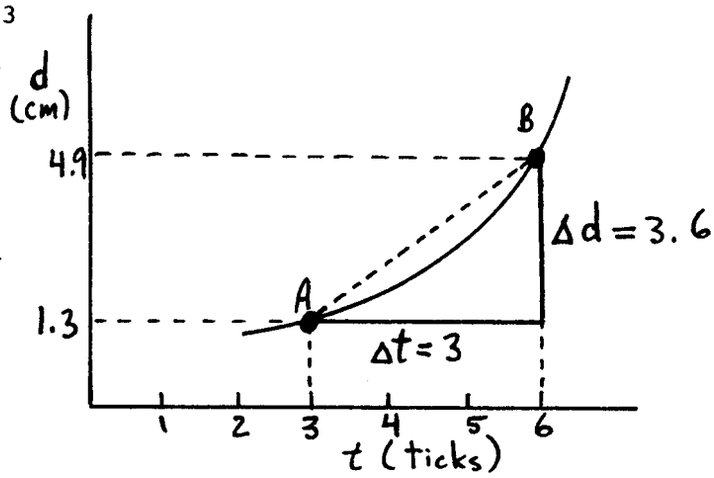
4. From the shape of your graph, what is the most probable relationship between position and time? Make a guess, and check it with your teacher.

5. What is the relationship between position and time for constant speed? Compare a constant speed graph with the graph of the position of the falling object.



In both cases the speed at any time is found by measuring the slope of the position versus time graph at that time. But you need a trick to find the slope of a curving graph at various points. First you find the average slope, $\Delta d/\Delta t$, during each successive time interval, and then you ask yourself where on each section of the curve the slope goes through its average value. This is the same as asking when in each time interval the continuously increasing speed goes through its average value.

Example: Let's say that between t = 3 ticks and t = 6 ticks on the curve at the right the position changes from 1.3 cm to 4.9 cm. Show that the average speed during this time interval is 1.2 cm/ticks, and that it occurs at about t = 4.5 ticks, the midpoint of the interval. (Dotted line AB has the average slope.)



6. Find Δ d from your previous data table and fill in the table on the next page. Then plot the speed versus time graph.

7. From the idealized shope of the speed versus time graph, deduce the relationship between speed and time.

8. What meaning can you assign to the slope of this graph?

The average acceleration during any time interval t is defined as:

$$\text{average acceleration} = a_{ave} = \Delta v / \Delta t$$

Note that the units of acceleration are those of a speed divided by a time, which always reduces to a distance divided by the product of two times:

(cm/ticks)/ticks = cm/ticks^2 OR (mi/hr)/s = mi/hr-s OR (m/s)/s = m/s^2

Whenever you're asked to solve for acceleration in a problem, make sure it comes out in units of acceleration such as these.

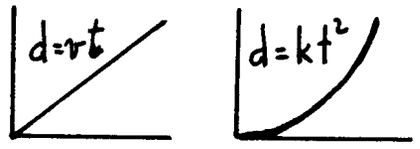
9. Find the average acceleration of your falling body in cm/ticks^2 and sketch a graph of acceleration versus time

KEY: Analysis of a Falling Body Tape

1 & 2. Expect anything from 1 to 5 ticks.

4. $d = kt^2$ (In a later worksheet, students find that k is 1/2 a. Don't let them assume that it is either the speed or the acceleration.

5. Example: $V_{average} = \Delta d/\Delta t = (4.9 - 1.3)cm/(3 - 6)$ ticks = 3.6/3 cm/ticks = 1.2 cm/tick. A ruler held tangent to the curve at t = 4.5 ticks is parallel to the dotted line AB. This is the only point on the curve where this happens.



7. $v = k't$ (or $v_f = v_i + k't$, if the straight line doesn't go through origin).

8. Slope = $\Delta v/\Delta t$ = average acceleration.

9. Expect the values for the acceleration to vary rather widely unless you are all using the same data, as from a strobe photograph. This makes for a good class discussion on how to account for the discrepancies. Two good reasons for discrepancies are:
   (1) not all timers tick at the same frequency.
   (2) difference in the amount of friction on the moving tape.

A good extra credit project:

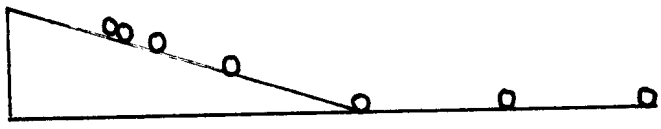
Students can make position, speed, and acceleration versus time graphs for their irregular horizontal motion. To find successive values of acceleration, add columns to the data table for Δv's and average acceleration (a_{ave}) It is quite likely that some of these values will be negative.

QUIZ ON GRAPHING STRAIGHT LINE MOTION NAME OF STUDENT: _____

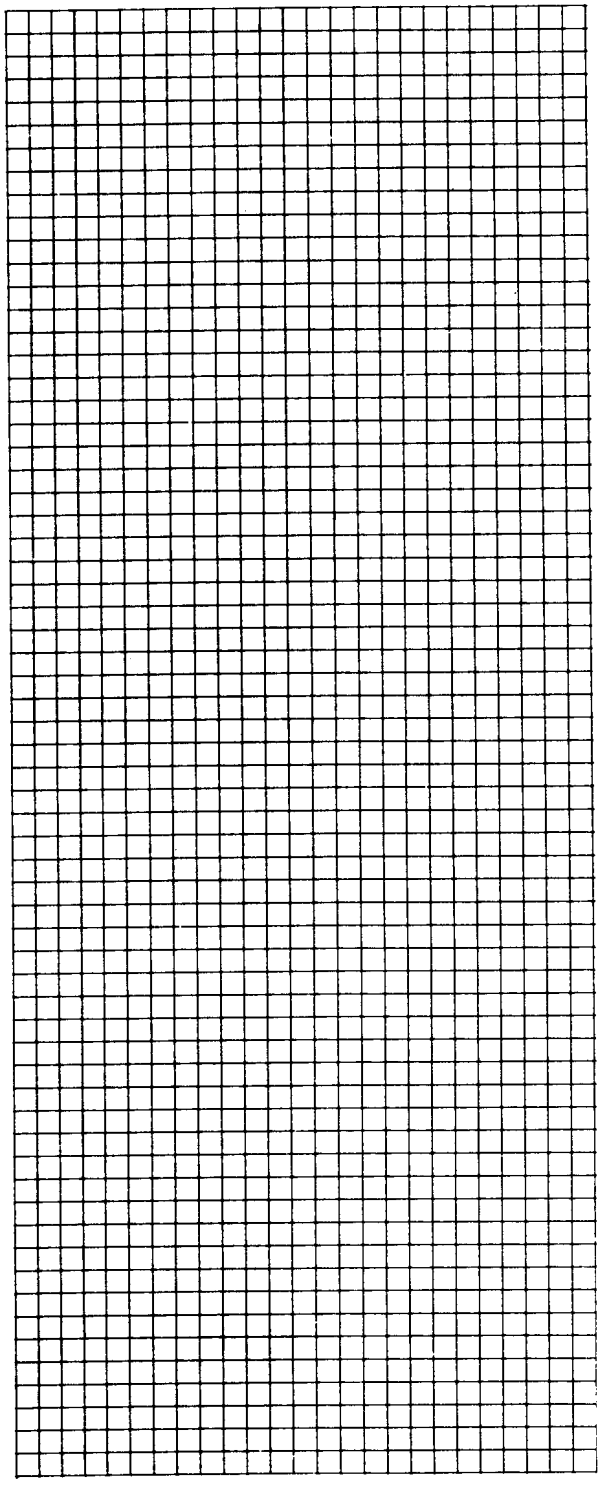
DATE_____ PERIOD: _____

A strobe light flashing 10 times per second is used to photograph a ball rolling down a gentle slope and then onto a flat surface. The time and position data are given in the table below.

Completely fill out the table and draw the three graphs on the right.



t (s)	d (cm)	Δd (cm)	v_{ave} (cm/s)	t_{mid} (s)	ΔV (cm/s)	a (cm/s²)
0	0					
		1.0		0.5		
0.1	1.0					
				1.5		
0.2	4.0					
0.3	9.0					
0.4	16.0					
0.5	23.5					
0.6	31.0					

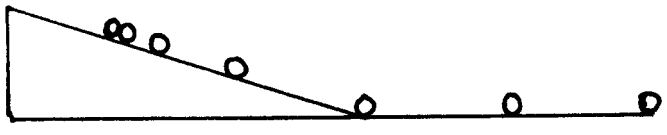


QUIZ ON GRAPHING STRAIGHT LINE MOTION NAME OF STUDENT: KEY

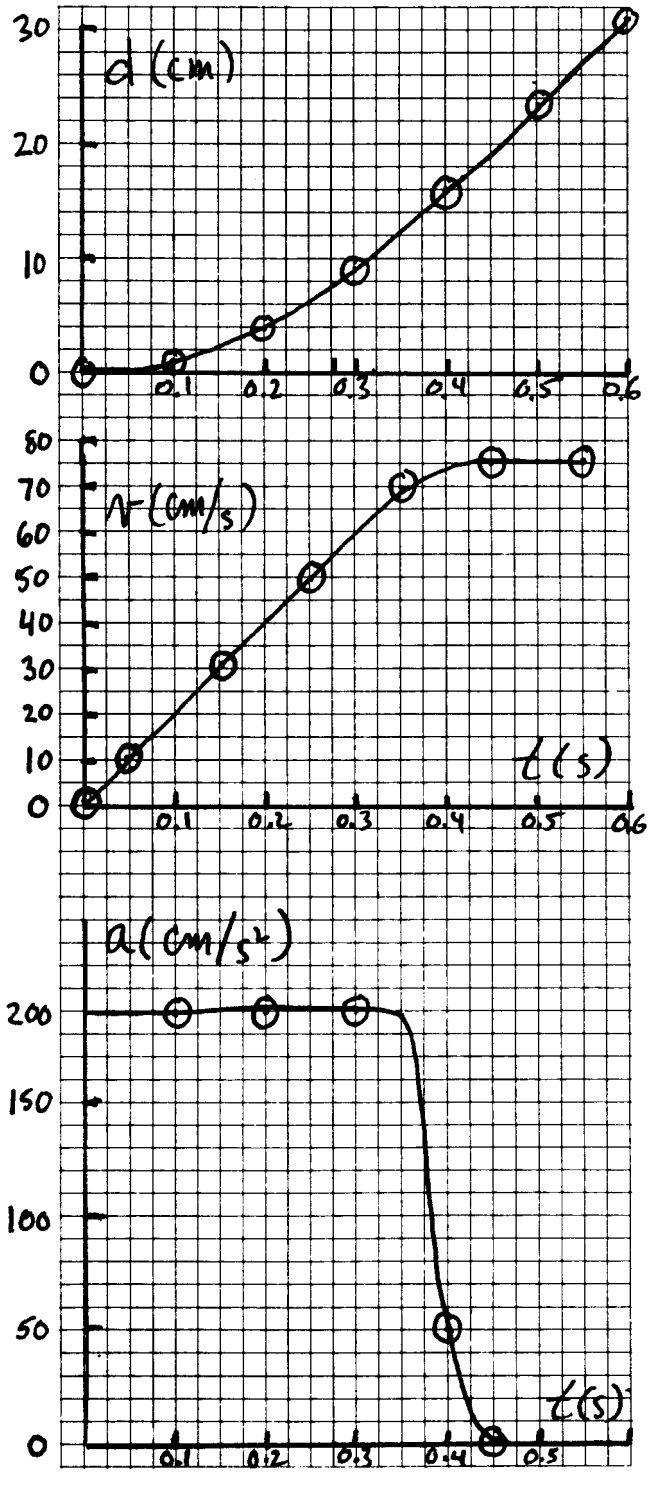
DATE_____ PERIOD: _____

A strobe light flashing 10 times per second is used to photograph a ball rolling down a gentle slope and then onto a flat surface. The time and position data are given in the table below.

Completely fill out the table and draw the three graphs on the right.



t (s)	d (cm)	Δd (cm)	v_{ave} (cm/s)	t_{mid} (s)	Δv (cm/s)	a (cm/s²)
0	0					
		1.0	10	0.05		
0.1	1.0				20	200
		3.0	30	0.15		
0.2	4.0				20	200
		5.0	50	0.25		
0.3	9.0				20	200
		7.0	70	0.35		
0.4	16.0				5	50
		7.5	75	0.45		
0.5	23.5				0	0
		7.5	75	0.55		
0.6	31.0					



Demonstrations with Falling Bodies

1. Demonstrations to show the effects of air resistance.

(a) Drop a textbook and a sheet of paper. Before dropping them, hold both horizontal and side by side. As the paper flutters to the floor, ask students if they can suggest any way to make the paper fall as fast as the book. Try anything they suggest. Try to get students to theorize about why the paper falls slower than the book. When they're convinced that size and shape make the difference, show that the book and a crumpled piece of paper fall with the same motion.

If you want to play a trick, bet students you can achieve a tie between book and paper without crumpling or otherwise altering the paper's pristine flatness. All you have to do is lay the paper on top of the book, being careful that no edges protrude over the sides, and drop them that way with a triumphant cry, "Geronimo!"

(b) It's sometimes true, as Aristotle taught, that heavy bodies fall faster than light ones. But is it always true? What about objects of the same size and shape but which have different weights? Try to locate several pairs of objects that fit this description (e.g. a golf ball and a Ping-Pong ball would be good, or a steel ball and a glass marble, or a book and an empty box.) You may not have a Tower of Pisa near at hand, but drop each pair of objects from as high a perch as you can. Will they hit simultaneously? Well..., if not, they're apt to be mighty close. And that, according to Galileo, was the important fact. Galileo believed, if the effect of the air could be eliminated entirely, all objects would fall with the same motion.

(c) There are commercial devices for demonstrating free fall in a vacuum. Usually they are long glass or plastic tubes with fittings for connecting them to a vacuum pump. The tube contains a coin and a feather. You might find such a apparatus in your storeroom. Unfortunately, the feather tends to rub the glass and becones electrically charged. When this happens the feather sticks to the tube and this has a greater effect on falling feather than air resistance. As memtion above, the paper lying on the book makes a very convincing case for Galileo's hypothesis.

2. Free fall acceleration is fast!

(a) Offer to give a dollar bill to any student who can catch it in free fall. Hold the bill by one end and then release the bill while the student prepares to grasp it with thumb and forefinger. The students should start with their finger opposite Washington's picture. Beware of the student anticipating the release!

(b) There are a number of experiments to measure the acceleration due to gravity. Since students have already analyzed a timer tape of a falling body, it is often interesting to have students use and compare several different methods for finding the acceleration due to gravity. (e.g. Attwood machine, direct timing, pendulum motion, inclined plane, et cetera)

3. Free fall acceleration is constant acceleration

(a) "Nuts in a pan!" Attach objects (e.g. bolt nuts, or lead sinkers) to a string (such as fishline). The first object should be about 10 or 15 cm from one end of the string. The second should be four times as far from the same end, the third 9 times, the fourth 16 times, the next 25 times, et cetera. Attach the end from which the measurements were made to a foil pan on the floor. Hold the string vertically, and let the objects drop. In spite of the increasing distances between the nuts, the sounds of their impacts are equally spaced. That could happen only with a constant acceleration. The argument is mathematical, and if the students don't buy it right away, tell them the next worksheet should convince them.

(b) The film loop Acceleration Due to Lunar Gravity, available from AAPT, shows an astronaut dropping a feather and a wrench side by side on the moon's airless surface. This is a very convincing demonstration. It also shows that the acceleration due to gravity on the moon is less than that on the earth.

C. Free fall and the Constant Acceleration Equations

The results learned from the class's falling body experiments may turn out neither very constant nor very close in value. It is only in the true free fall that the acceleration is both constant and the same for all bodies in a given location. Free fall means fall without air resistance, friction, or any other factor besides the pull of gravity affecting the motion, and that can only be approximated in real life. The astronaut who dropped a feather and a wrench on the airless moon to show that they fell together got about as close as nature allows.

There are many simple demonstrations you can do to show the effects, both very large and very small, of air resistance on falling bodies of different weights and shapes. The surprising thing, as Galileo pointed out, is how nearly together compact objects do fall through the earth's atmosphere. Like constant speed, constant acceleration is not easy to achieve by mechanical means, so when you want to produce it as nearly as possible in the laboratory, you let gravity do the work.

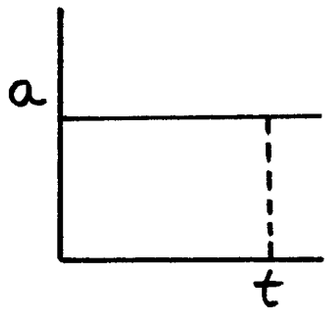
But if a truly constant acceleration is rare in real life, the average acceleration can be used as a convenient substitute constant, just as average speed subsumes all the variations of speed during a race or trip. Using average acceleration makes it possible to derive some very useful equations relating distance, initial and final speed, and time in accelerated motion.

Students have already learned something about these equations from their falling body analysis. (e.g. if acceleration is constant enough it is justified to use an average value over the whole time span; and change in speed is proportional to time, and when a body starts from rest the distance moved is proportional to the square of the time of motion.) The following worksheet presents a more general and complete derivation. It is also graphically based, but relies on the area under the graphs rather than the slopes.

NAME OF STUDENT: _____

DATE DUE: _____ PERIOD: _____

WORKSHEET ON CONSTANT ACCELERATION -- A VERY SPECIAL CASE



The graph on the left describes a special kind of motion: constant acceleration in a straight line. On this worksheet you are going to derive four equations that will prove useful for doing problems concerned with this type of motion

We begin by finding the area under the acceleration versus time graph from 0 to t. The shape is a rectangle with base t and altitude a thus the area is given by:

$$\text{area} = at$$

Note that if area = Δv, this is the same as: $a = \Delta v / \Delta t$.

1) If a = 6 mi/hr-s and t = 5 s, how much has the speed changed during the 5 second time interval? v = _____

2) If v_{final} = 50 mi/hr, what was $v_{initial}$? v_i = _____

NOTE: We will use v_f to represent v_{final} and v_i for $v_{initial}$.

Write the algebraic equation for v_f in terms of v_i, a, and t.

<u>Equation 1</u> v_f =

Equation 1 tell you the speed of an object which has a certain acceleration and initial speed. Compare equation 1 with the equation for a straight line, y = mx + b, where m is the slope and b is the y-intercept. This tells you that when you draw a speed versus time graph for a constant acceleration situation, it will be a straight line with slope ____ and intercept _____ . Draw such a graph.

On your speed versus time graph, pick a time t and extend a line upward until it intersects the graph. The area enclosed is a trapezoid with bases v_f and v_i and height t. Write the equation for the area. (If you don't remember the trapezoid area equation, try to derive it from the sum of a rectangle and a triangle.) What quantity does this area represent? _____ Assuming that $d_i = 0$, so that $d_f = d$, write a general equation for d in terms of v_f, v_i, and t.

<u>Equation 2</u> d =

Equation 2 tell you the distance traveled by an object which has been accelerating for a specified time. If you now do some algebraic substituting with Equations 1 and 2, you'll get two new equations which will save you doing the algebra all over again each time you get a problem to solve.

(a) Eliminate v_f in equation 2 by substituting its equivalent from equation 1. Simplify to get

<u>Equation 3</u> d =

(b) Eliminate t in equation 2 by solving equation 1 for t and substituting.

<u>Equation 4</u> $v_f^2 =$

You might like to transfer these four equations to a reference sheet. Here are some tips on how to use them when solving any problems in which the acceleration is or is assumed to be constant.

1. Always notice whether a problem states or implies that the moving object starts from rest. If so, then $v_i = 0$, which simplifies the four general equations into shorter forms. You may want to add these simplified versions to your reference sheet.

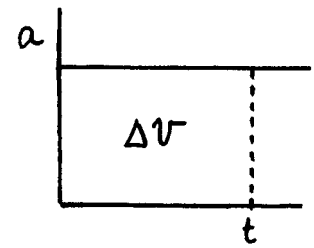
2. How can you decide which equation to use to help you solve a constant acceleration problem? Notice that in the general equations there are five quantities to consider: v_f, v_i, a, d, and t. But each of the equations contains only four of these five. And a problem will give you values for only three, and ask you to find the fourth. It says nothing at all about the fifth quantity. So pick the equation that does not contain the missing quantity and you should be home free. (Of course you can always do them in two steps with just Equations 1 and 2.)

   For instance, if you aren't given the time but are supposed to find v_f, use equation 4. No value for d? Use equation 1. When the acceleration isn't given, equation 2 does the job, while equation 3 does not need v_f.

3. If you aren't told what the acceleration is, but it's a falling body problem here on earth, your're supposed to know that the acceleration is downward, and has a value of 9.8 m/s^2.

KEY: Worksheet on Constant Acceleration

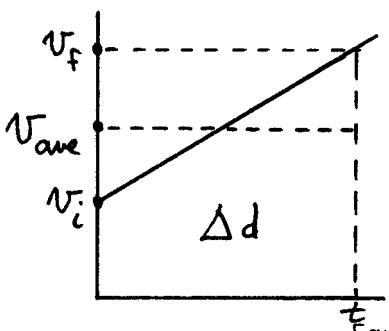
area = at = $\Delta v/(\Delta t) * t = \Delta v/t * t$ (since $\Delta t = t$ when $t_i = 0$)
$= \Delta v$



1) $\Delta v = at = (6 \text{ mi/hr-s}) \times 5 \text{ s} = 30 \text{ mi/hr} = v_f - v_i$

2) $50 \text{ mi/hr} - v_i = 30 \text{ mi/hr}$ thus $v_i = 20 \text{ mi/hr}$

<u>Equation 1</u> $v_f = v_i + at$



Equation 1 is a straight line with slope a and y-intercept v_i.

Trapezoid area = $((v_f + v_i)/2)t = v_{ave}t = \Delta d$
(will = d if $d_i = 0$)

<u>Equation 2</u> $d = (v_f + v_i)/2 \times t = v_{ave}t$

(a) $d = ((v_i + at) + v_i)/2 \quad t = ((2v_i + at)t)/2 =$
<u>Equation 3</u> $v_i t + (1/2)at^2$

(b) From equation 1, $at = v_f - v_i$; $t = (v_f - v_i)/a$

Substituting: $d = (v_f - v_i)/2*(v_f + v_i)/a = (v_f^2 - v_i^2)/2a$

<u>Equation 4</u> $v_f^2 - v_i^2 = 2ad$

REFERENCE SHEET SUMMARY

General form of the equation	Special case when $v_i = 0$
1. $v_f = v_i + at$	$v = at$
2. $d = ((v_f + v_i)/2)t = v_{ave}t$	$d = v_f t/2$
3. $d = v_i t + (1/2)at^2$	$d = (1/2)at^2$
4. $v_f^2 - v_i^2 = 2ad$	$v_f^2 = 2ad$

QUIZ ON STRAIGHT LINE MOTION EQUATIONS NAME OF STUDENT: _____

DATE_____ PERIOD: _____

1. A car's speed is 80 km/hr. How far will it travel in 10 minutes?

   (a) 8 km (b) 800 km (c) 13 km (d) 48 km (e) 480 km

   Answer _____

2. A small airplane's takeoff speed is 30 m/s. With constant acceleration it takes 150 m of runway to become airborne. How long does it take to become airborne?

   (a) 30 s (b) 10 s (c) 5 s (d) 0.2 s (e) 8 s

   Answer _____

3. An auto parked on a hill starts rolling, picking up speed steadily. After the first 5 seconds it is moving at a speed of 10 m/s. The distance it has rolled is

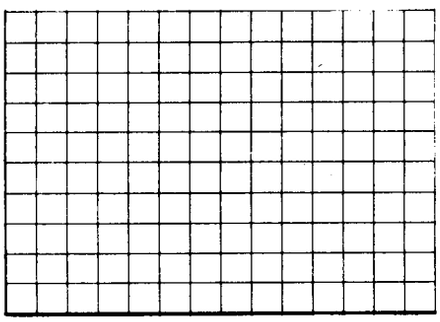
   (a) 0.5 m (b) 2.0 m (c) 25 m (d) 50 m (e) 250 m

   Answer _____

4. A car is following a slow trailer at a speed of 10 m/s. At last the road clears and the driver accelerates, passing the trailer traveling at a speed of 16 m/s. How far did the car travel in the six seconds it took to pass the truck?

   (a) 60 m (b) 78 m (c) 96 m (d) 156 m (e) 256 m

   Answer _____

5. 

A skier moves downslope, starting from rest, with an acceleration of 2 m/s^2. At the end of 6 seconds he slows down to a stop, which takes 1 second more.

(a) On the graph outline on the left, draw a graph showing how the skier's speed varies with time.

For parts (b), (c), and (d) show your work:

(b) What is the skier's maximum speed?

Answer _____

(c) What was the skier's acceleration while stopping?

Answer _____

(d) What total distance did the skier travel?

Answer _____

QUIZ ON STRAIGHT LINE MOTION EQUATIONS NAME OF STUDENT: KEY

DATE_____ PERIOD: _____

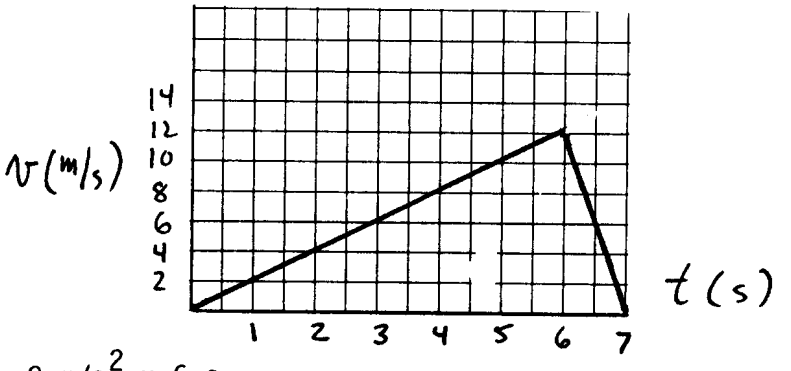
1. $d = vt = 80\ km/hr \times 10\ min \times 1\ hr/60\ min = 13\ km$ Ans. c

2. $d = v_{ave}t \quad t = d/v_{ave} = 150\ m/15\ m/s = 10\ s$ Ans. b

3. $d = v_{ave}t = 5\ m/s \times 5\ s = 25\ m$ Ans. c

4. $d = v_{ave}t = (((10 + 16)m)/2\ s) \times 6\ s = 78\ m$ Ans. b

5. (a)



5. (b) $v_f = at = 2\ m/s^2 \times 6\ s$ Ans. 12 m/s

5. (c) $a = \Delta v/\Delta t = (-12\ m/s)/\ 1\ s$ Ans. $-12\ m/s^2$

5. (d) area = d = (1/2)*7 s x 12 m/s Ans. 42 m

D. Hopscotching from Graph to Graph

You've introduce students to the concepts of slope and area using the graphs they've made for their experiments. Now is a good time to review. The sample sets of motion graphs on the worksheet on the next page illustrate a kind of puzzle that students may enjoy solving: given any one of the graphs in a distance, speed, acceleration set, reconstruct the other two graphs and describe the motion in words.

Students will need lots of practice going down the columns taking slopes, as in set 1. The fascinating thing is that they can also learn to start at the bottom of the column and reconstruct their way back up to the top, using the concept of area under the curve, as shown in set 2. Or they can start in the middle and go both ways, as in set 3.

Your text is bound to have lots of examples which you can assign once the two concepts of finding area and slope are clear, but it would probably be wise to start with some good class discussion in which you and the students verbalize the process.

Hang on to these rules:

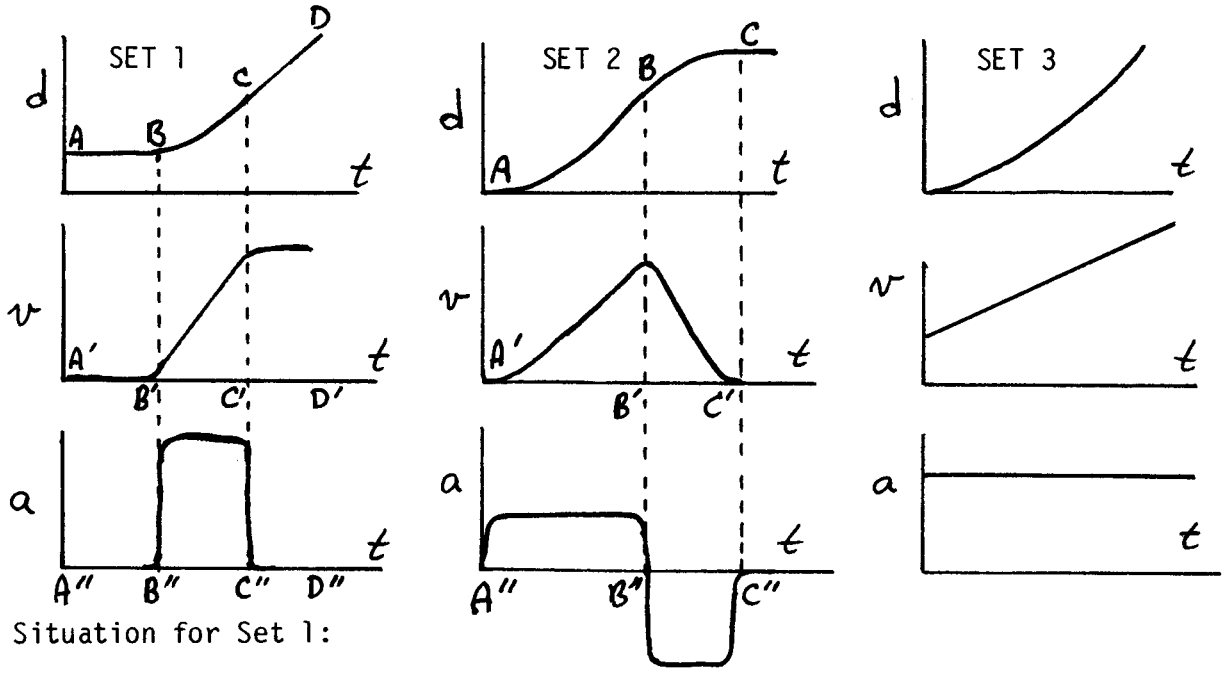
The slope of d = v
the slope of v = a

the area under a versus time = change in v
the area under v versus time = change in d.

Area above the horizontal axis implies an increase; "negative" area below the axis implies a decrease. Using these rules, you and your students can talk your way from graph to graph on the following worksheet.

WORKSHEET ON HOPSCOTCHING FROM GRAPH TO GRAPH

Study the three sets of graphs below. Each set describes a different motion. Invent a short scenario for each set. (For example, Set 3 shows constant acceleration starting from an initial speed. What could be going on?)



1. Situation for Set 1:

2. Situation for Set 2:

3. Situation for Set 3:

Each of the three graphs in any one set tells the same story. If you start at the top with the position versus time graph only, you can derive the other two by taking slopes, as in Set 1. If you're given the acceleration graph only, you can reconstruct your way back up to the top by using the concept of area under the curve, as in Set 2. Or finally, as in Set 3, you can start in the middle and go both ways.

The trick is to say to yourself in words what the key graph is doing, then translate your words into the next graph. In graph 1, Set 1, for example, the slope from A to B is zero, so v must be zero from A' to B'. From B to C the slope is steadily increasing, so v must be increasing. And finally, the slope from C to D is constant, so v must be constant from C' to D'.

4. Explain in words why the acceleration versus time graph in Set 1 has the shape it does.

Going up the columns taking areas, instead of going down taking slopes, you need some additional information. For example, look at the bottom graph in set 1. If you assume that v was zero to start with at A", then it is still zero at B', since there was no acceleration. By how much did v increase from B" to C"? By finding the area under the acceleration blip, you learn how far up the v axis you should put C'. And since a is constant from B" to C", the slope of speed versus time must be constant between B' and C'. From there on there is no more area under the acceleration versus time graph, so there is no more Δv, and v becomes constant at its C' value.

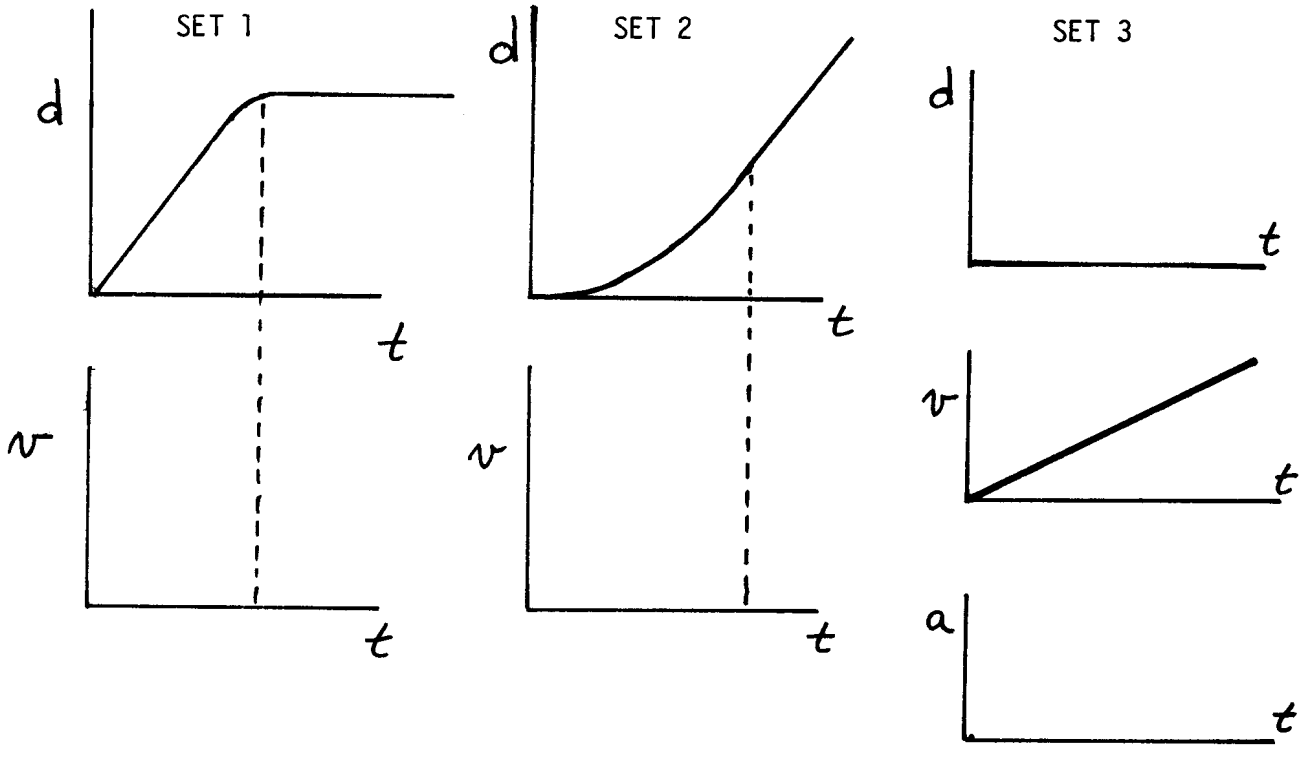
5. Explain in words how points B and C are found on the top graph of Set 2, using the information from the speed versus time graph of that set.

6. In the acceleration versus time graph of set 2, area 1 is positive, but area 2 is negative. How is this information used to reconstruct the corresponding speed versus time graph?

QUIZ ON GRAPH HOPSCOTCHING NAME OF STUDENT: _____

DATE_____ PERIOD: _____

Reconstruct the missing graphs in each of the following sets:



For each set, describe the motion in words.

1.

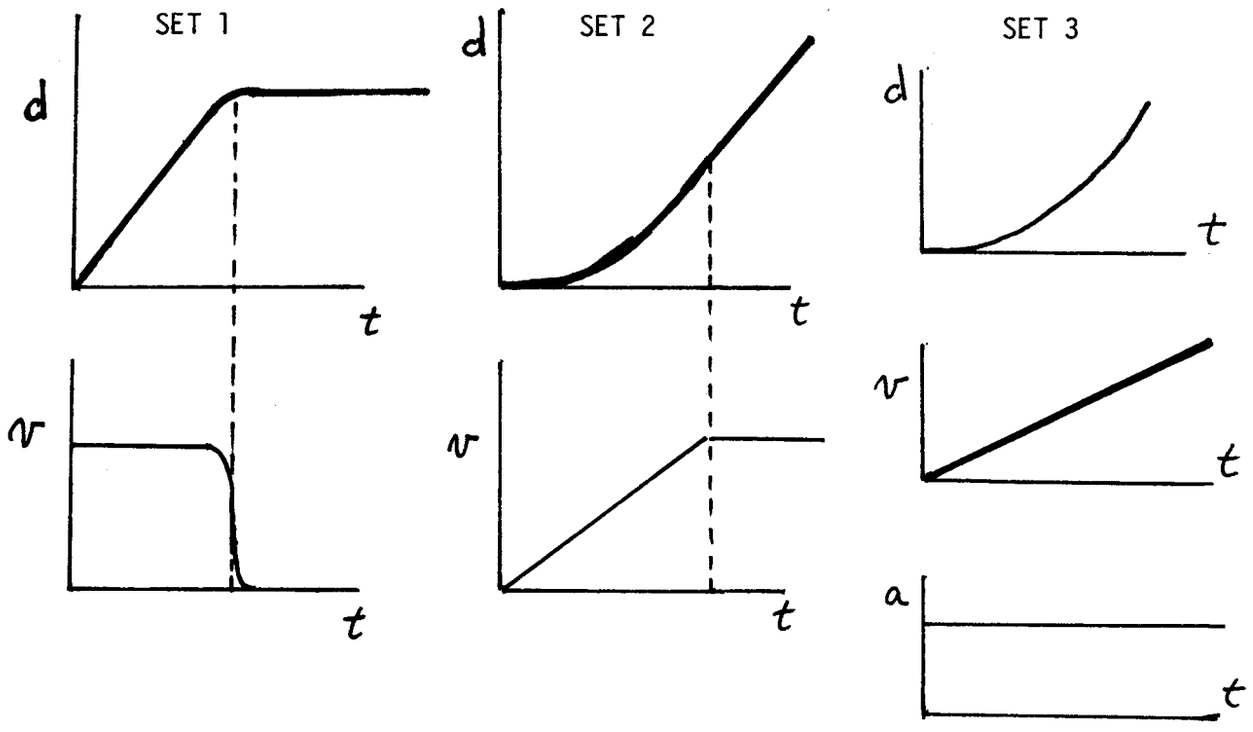
2.

3.

QUIZ ON GRAPH HOPSCOTCHING NAME OF STUDENT: KEY

DATE_____ PERIOD: _____

Reconstruct the missing graphs in each of the following sets:



1. A car moving with constant speed for a while comes to a stop.

2. A car accelerates from zero up to speed v, then continues at that speed.

3. A body starts from rest and accelerates at a constant rate.

E. Taking Direction into Account

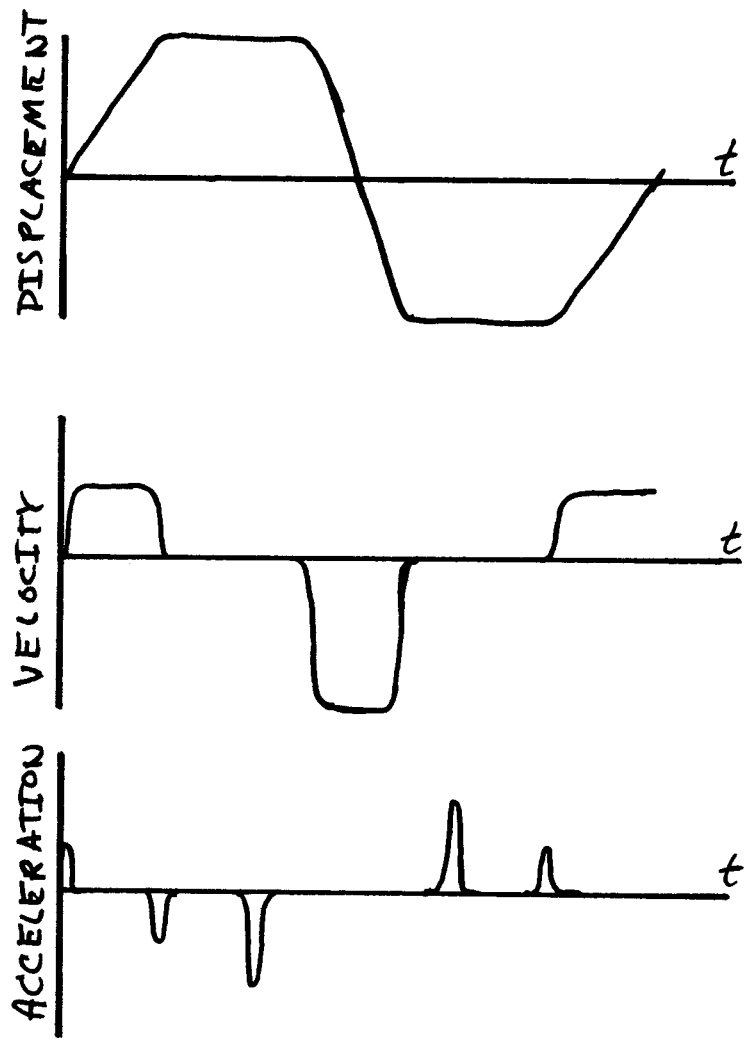
Straight line motion is not always a one-way proposition. One can go west as well as east; down as well as up; leave home and come back in the same trip; or continue to move back and forth around a central position. We need some simple way to keep track of what's going on, and fortunately there is one.

You decide, quite arbitrarily, to call one direction along a line of motion the positive direction, and the opposite direction is then negative. If you make the direction up positive, then down must be negative. If distance to the right of a given point is on the positive side, then distance to the left of the point is negative.

1. Distance versus Displacement

When you go on a round trip, you end where you started. Your final displacement is zero, although the total distance you traveled is not. Displacement measures how far and in what direction you are from your starting point, with no concern for how far you went to get there. In this case the displacement and average speed are both ZERO!

The top graph on the right records displacement rather than position for a body that started out in one direction, stopped for a while, turned around and went back past its starting position and on a bit further in the opposite direction, stopped again, and finally turned around and came back home.



2. Speed versus Velocity

Given a positive direction for displacement, speed in that direction is also positive, and speed in the opposite direction now becomes negative. When you take account of its direction, you describe the motion as velocity rather than speed. Speed is what you read on the speedometer of your car; it doesn't care which way you're heading. Velocity, like displacement, includes direction and is called a vector quantity in physics. Vectors MUST have a direction!

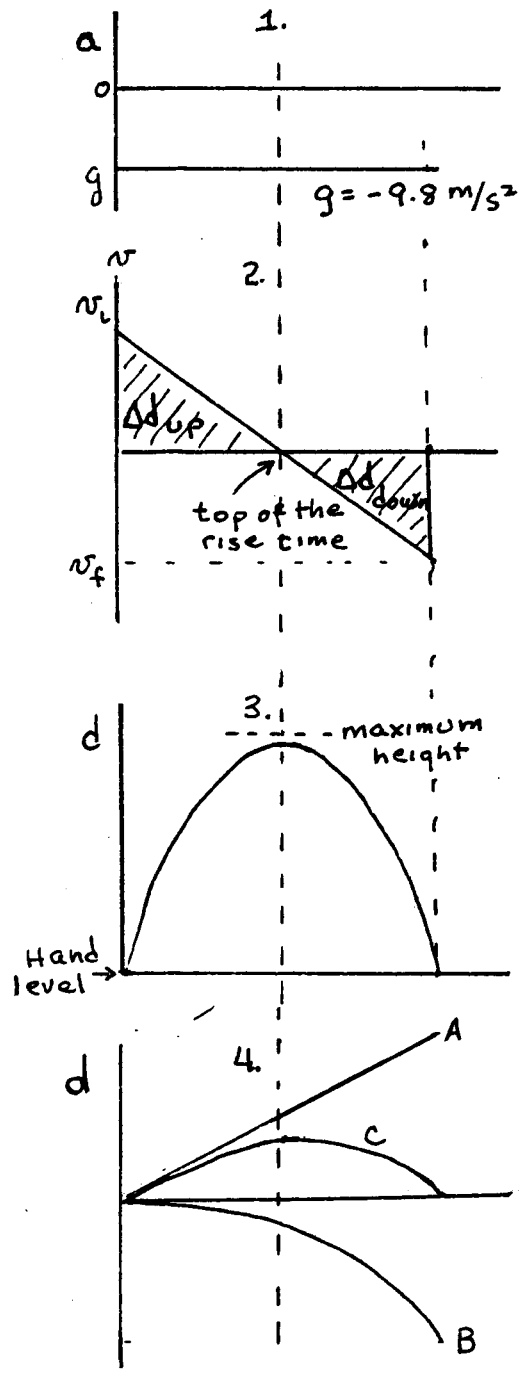
To distinguish in writing between distance & displacement, and between speed & velocity, add a little arrow above the vector version. For example d has no direction, d does; v is represents speed, while v represents velocity. Textbooks tend to use boldface type rather than arrow caps to indicate that direction is important and the quantity is a vector.

You should not be surprised to learn that acceleration is also a vector quantity, and it's tricky to decide whether acceleration is positive or negative in some situations. For instance, if you're slowing down in the positive direction or <u>speeding up in the negative direction,</u> the acceleration is negative in both cases! When you need to, the easiest way to tell is to look at the slope of the velocity versus time graph.

Another thing to notice about acceleration is that in most everyday situations, like walking or driving, changes in velocity take place in seconds, or even fractions of seconds. This is a very short time interval compared to those recorded for velocity. Thus an acceleration versus time graph is often just a series of narrow + and - blips along the time axis, making it look strange indeed, see the bottom graph on the previous page.

F. Projectiles - What Goes Up Comes Back Down

When direction is taken into account, you can progress beyond falling bodies and begin to track the motion of balls thrown straight upwards with some given initial velocity. How high will they go? How long before they fall back to your hand? And so on. No longer are displacement, velocity, and acceleration all in the same direction. If you decide to call distance above the ground positive, then you must call the constant downward gravitational acceleration negative. At the top of the rise the velocity, momentarily zero, is changing from positive (upwards) to negative (downwards), thus the acceleration is still $-9.8\ m/s^2$.



The three graphs of the motion of a ball tossed straight up reveal some symmetries. With constant negative acceleration (graph 1) the velocity versus time graph must be a straight line sloping downward from v_i (graph 2). Its intersection with the t axis tells how long it took to reach the top, and the area of the triangle formed gives us the height reached. But distance up must equal distance down, so the triangle on the negative side must be congruent to the first triangle. Result: $t_{up} = t_{down}$ and $v_f = -v_i$. The speed lost going up is gained back coming down, and the time is the same for going up and coming down.

The equations of motion with constant acceleration confirm these conclusions. For the round trip, final displacement Δd is zero. Plugging that in, one gets round trip time $t = 2(v_i/-g)$, and $v_f = -v_i$.

The equation for the third graph is:

$$d = v_i t - (4.9\ m/s^2)t^2$$

This equation actually gives the sum (C) of two graphs:

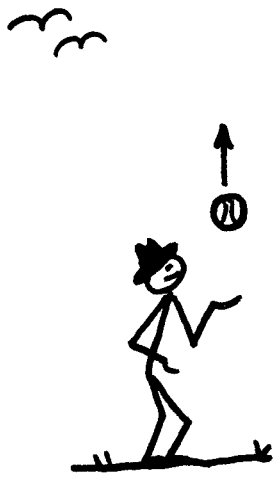
A the straight line $d = v_i t$ showing how high the body would go in time t if its velocity were constant,
plus the negative curve B showing distance fallen in time t if dropped from rest.

It would probably be best to allow students to work out these relationships for themselves. Before they start, discuss with them how to take distance into account when the motion is in two directions along a straight line. The worksheet which follows may then be useful.

NAME OF STUDENT: _____

DATE DUE: _____ PERIOD: _____

WORKSHEET ON GOING UP AND COMING DOWN



Think of tossing a ball straight upwards and catching it when it falls back down. It leaves your hand with some initial velocity v_i. How high will it go? How long will it be in the air? Which takes longer, going up or coming down? What will its final velocity be when you catch it? You can reason out the answers to these questions by using what you know about the effect of gravity on unsupported objects, about graphical analysis, and about the four equations of motion with constant acceleration. (By assuming negligible air resistance, we can say the acceleration is constant.)

First you must be very clear about the role your hand plays. It accelerates the ball from rest to whatever velocity you give it; and when you catch it you decelerate it back to rest from whatever downward velocity it has acquired in its fall. But in between, while the ball is in flight, you have no influence on it at all. It's the in-between part that this worksheet is about.

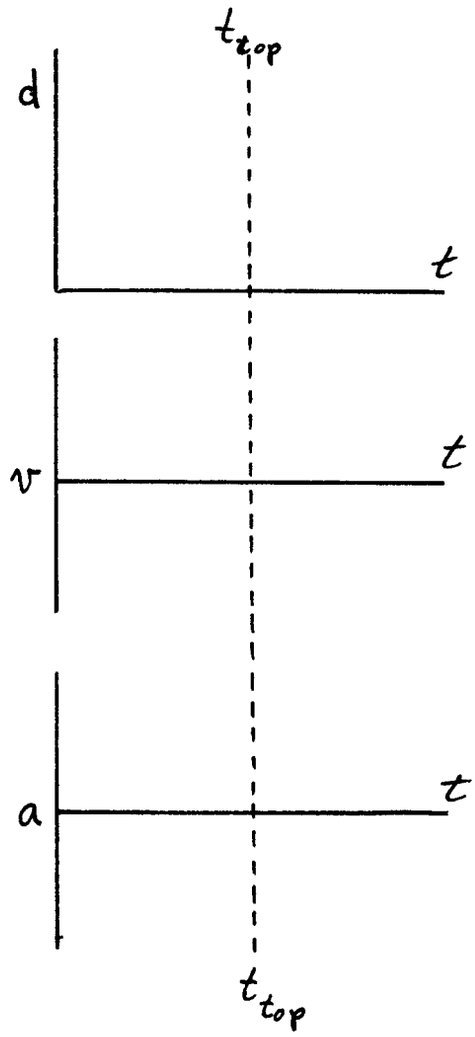
The next thing to think about is direction. It's customary to designate the upward displacement above your hand as positive. Then Δd going up is positive, making the upward velocity also positive. Coming down, Δd from your hand is positive making the <u>average</u> velocity positive; however, the downward velocity is negative.

1a. What about g, the acceleration due to gravity? You know its value and direction when the ball is falling: g = _____.

1b. What is the value and direction of g when the ball is rising?

1c. What is the value and direction of g when the ball is at the top of the rise?

Graphical Analysis



2. Draw the graph of g versus t. What does it tell you about the slope of the velocity versus time graph?

3. The vertical dotted line through all three graphs indicates an arbitrary time at which the ball reaches its maximum height (i.e. t_{top}). What's the value of speed at that time?

   Plot a point on the velocity versus time graph for t_{top} the corresponding velocity. Add an arbitrary point for v_i somewhere on the v-axis. Then draw the velocity versus time graph.

4. Choose a maximum height and put it on the position axis of the position versus time graph. From the slope of the velocity versus time graph, reason out the shape of the rising part of the position graph, then the falling part. Draw the position versus time graph. (Although this looks like a trajectory, the path followed by the ball is straight up and down.)

5. You can use the areas under the velocity versus time graph to learn something about how v_f compares to v_i, and how Δt_{down} compares to the Δt_{up}. The area from 0 to t_{top} is positive. It represents a change in what quantity?
Write an equation for this: _____ .

6. The area under the velocity versus time graph from t_{top} to t_{final} is negative. What is the significance of the negative area in terms of displacement?

7. Assuming you launch and catch a ball at the same level, how should the two areas on the velocity versus time graph compare?

   Where should you mark t_{final}? Do this and then find v_f. Put v_f on the v-axis.

8. In algebraic terms write the relationship between v_f and v_i; and between Δt_{up} and t_{down}.

You can get the same information and a little bit more by using your four equations of motion with constant acceleration. For extra credit, put d_f, the final displacement, equal to zero in equations 3 and 4, and see what happens. (You should get an equation for v_f, and for total time of flight.) To learn about the upward half of the trip, set v_f equal to zero in equation 2 to find maximum height, or in equation 3 to find the time to reach the top of the rise.

<u>Sample problems</u>: 1. A projectile leaves a launcher going 30 m/s straight up.

(a) How long does it take to reach maximum height? Let $g = -10\ m/s^2$.

(b) How high will the projectile go?

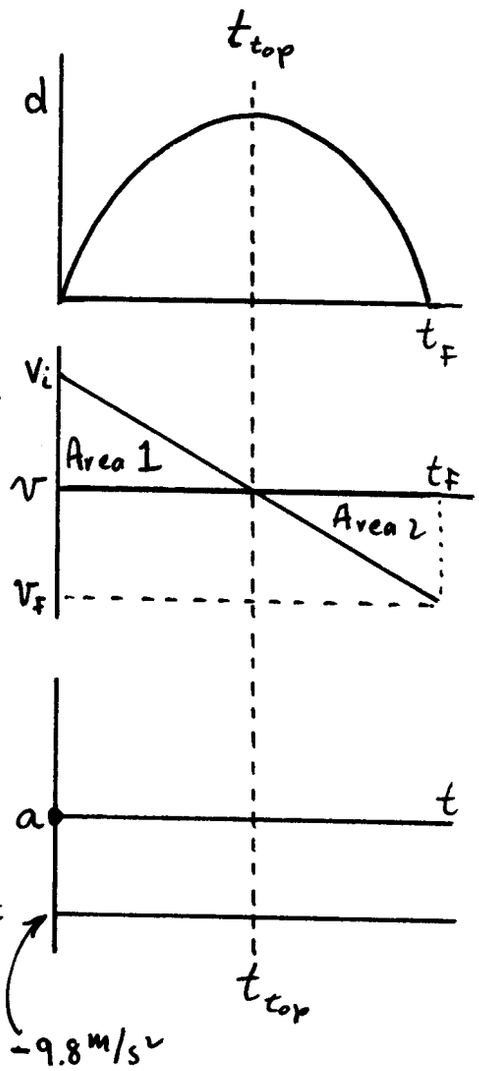
(c) What is the total time of flight?

(d) What is the final velocity?

(e) What velocity will the projectile have when it is 25 meters above the launcher? Is there more than one answer?

2. You can do this one in your head. If a car going 30 mi/hr loses 10 mi/hr every second, how long does it take to come to a stop?

KEY: Worksheet on Going Up and Coming Down



1. $g = -9.8\ m/s^2$ everywhere.

2. Constant negative acceleration means velocity versus time graph must have constant negative slope.

3. The value of speed at maximum height is momentarily 0.

4. See graphs to the right

5. Area 1 represents the total upward displacement. Equation: area = $d_{maximum} = 1/2\ t_{up} * v_i$

6. A negative area means that the displacement has decreased. In other words, the ball has come back down.

7. The two areas must be equal, so the two triangles must be congruent.

8. $\Delta t_{up} = \Delta t_{down}$, and $v_f = -v_i$ (if starting and final heights are the same).

EXTRA CREDIT: Using the four constant acceleration equations:

a. $v_f^2 - v_i^2 = 2ad = 0$, so $v_f = -v_i$.
$v_i t_f + (1/2)at_f^2 = 0$, so $t_{f/2} = v_i/g$

b. $d_{maximum} = v_{ave} t = (v_i/2)t_{top}$.
$v_i + at_{top} = 0$. so $t_{top} = -v_i/g$.

Sample problem:

a. $t = 3$ seconds

b. $d = v_{ave}t = 15\ m/s \times 3\ s = 45\ m$

c. Total $t = 2t_{top} = 6$ seconds

d. $v_f = -v_i = -30\ m/s$

e. $v_f^2 = v_i^2 + 2gd = (30\ m/s)^2 - (20\ m/s^2 * 25\ m)$
$= 900\ m^2/s^2 - 500\ m^2/s^2 = 400\ m^2/s^2$ thus $v_f = 20\ m/s$.

Yes! The projectile could be either rising or falling at a height of 25 meters.

QUIZ ON GOING UP AND COMING DOWN NAME OF STUDENT: _____

DATE_____ PERIOD: _____

1. A ball is projected straight upward. When it is at its highest point its acceleration
   (a) is zero and its velocity is downward.
   (b) is downward and its velocity is zero.
   (c) and velocity are both downward.
   (d) and velocity are both zero.
   (e) and velocity are both upward.

Answer _____

2. A stone is dropped from a bridge and is seen to splash in the water 3 seconds after it was released. How high is the bridge above the water?

(a) 15 m (b) 30 m (c) 45 m (d) 90 m (e) 125 m

Answer _____

3. A ball thrown straight upward strikes the ground 4 seconds later. How high did it rise?

(a) 20 m (b) 40 m (c) 80 m (d) 125 m (e) 160 m

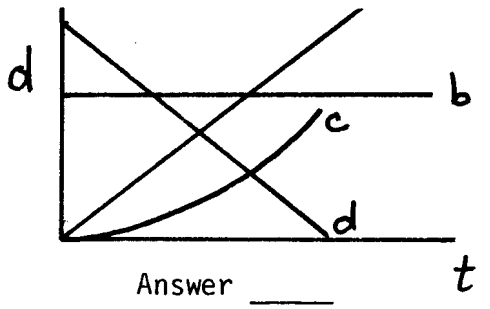
Answer _____

4. If a marble rolling with constant acceleration down an incline moves 6 cm in the first second, then at the end of 3 seconds it will have travelled a total distance of

(a) 18 cm (b) 36 cm (c) 54 cm (d) 108 cm (e) 120 cm

Answer _____

5. Which of the graphs shown at the right would represent the relationship between the time and the position of a freely falling body?



Answer _____

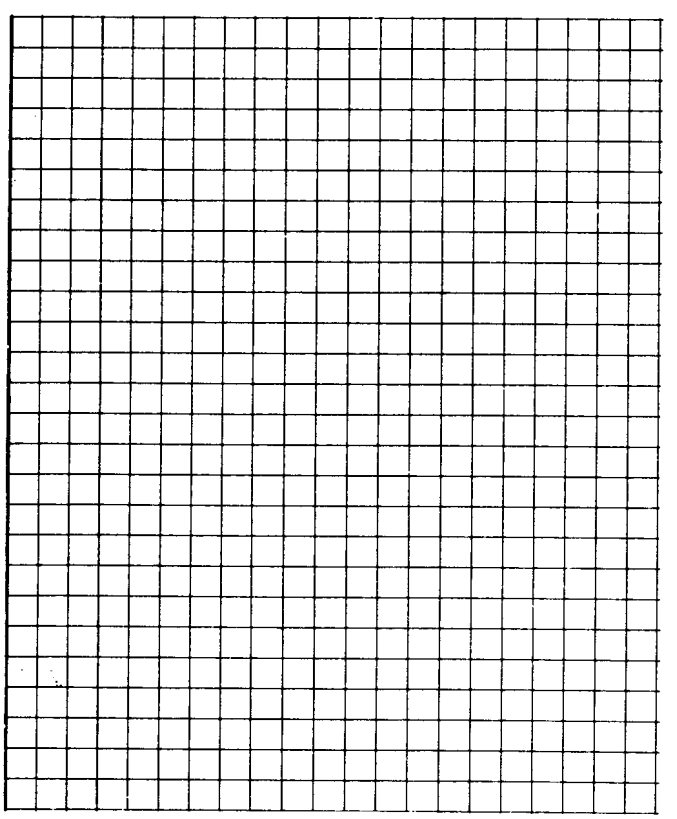
6. During a physics experiment a ball is allowed to roll from rest down a 100-cm incline. Students take the following time and position data:

d (from top) [cm]	t (from start) [seconds]
0	0
20	2.1
40	3.0
60	3.7
80	4.2
100	4.7

(a) Draw a graph of these data.

(b) From your graph, determine how far the ball had rolled in 4 seconds. On the graph show how you determined this.

(c) What was the ball's acceleration on the incline? (Show all your work.)



QUIZ ON GOING UP AND COMING DOWN NAME OF STUDENT: _____

DATE_____ PERIOD: _____

1. b

2. c

3. a

4. c

5. c

6. a

6.(b) 72 cm

6.(c) $a = 2d/t^2 = 200cm/(4.7s)^2$ or $120/(3.7s)^2$ or....

Answers will be about 9 cm/s^2, depending on choice of data.

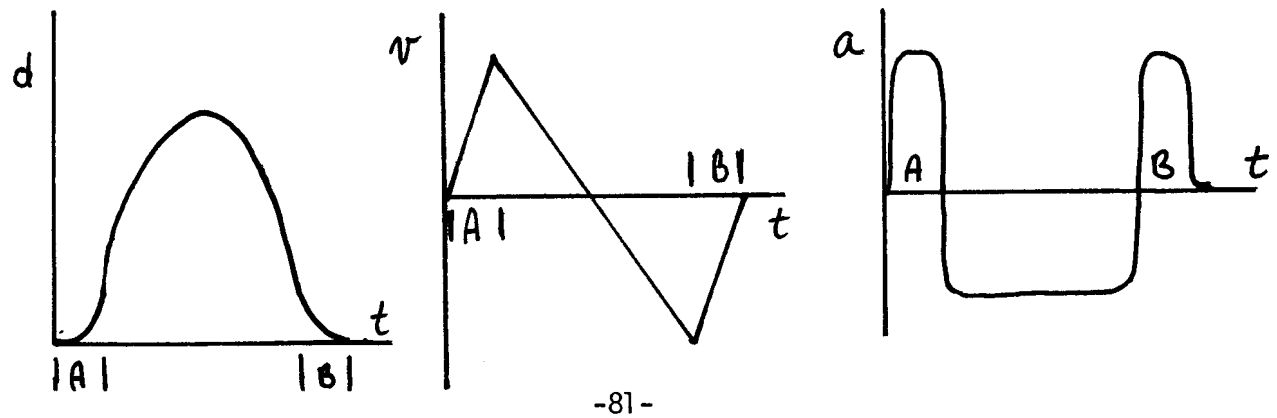
Additional things to do and discuss with your class

1. How could you measure the acceleration of a car using the speedometer and your watch? Would this method work for deceleration?

   Decide on a period of time (e.g. 5 seconds) during which the acceleration is to be measured. Note the speed at the beginning and end of the interval and subtract these values to find the change in speed. For example, if the speed changes from 20 to 45 mi/hr in 5 seconds, the acceleration is 25 mi/hr divided by the time, or 5 mi/hr-s. The same method can be used for deceleration, but the change in speed would be negative, giving a negative acceleration.

2. Students have already graphed the motion of a ball tossed straight upward from the time it leaves the hand until it falls back to the hand. What changes would have to be made in the graphs to describe the motion from the time when the ball is at rest in the hand to the time it's at rest after catching it?

   As the ball is thrown, it has a large upward acceleration over a short distance until it leaves the hand. At the instant it is caught the hand again supplies a large upward acceleration to the downward moving ball, bringing it to rest. On the graphs below the intervals marked A and B are the needed additions.



3. Draw velocity versus time and acceleration versus time graphs for each of the following:

(a) You start the car at the curb and drive down the street at constant speed.

(b) You are driving behind a slow truck when the road ahead clears and you pass the truck.

(c) You stub your toe!

(d) A soft rubber ball is dropped and bounces off the floor. The height of the bounce is not quite as high as the original height.

QUIZ ON GRAPHS WITH DIRECTION NAME OF STUDENT: _____

DATE_____ PERIOD: _____

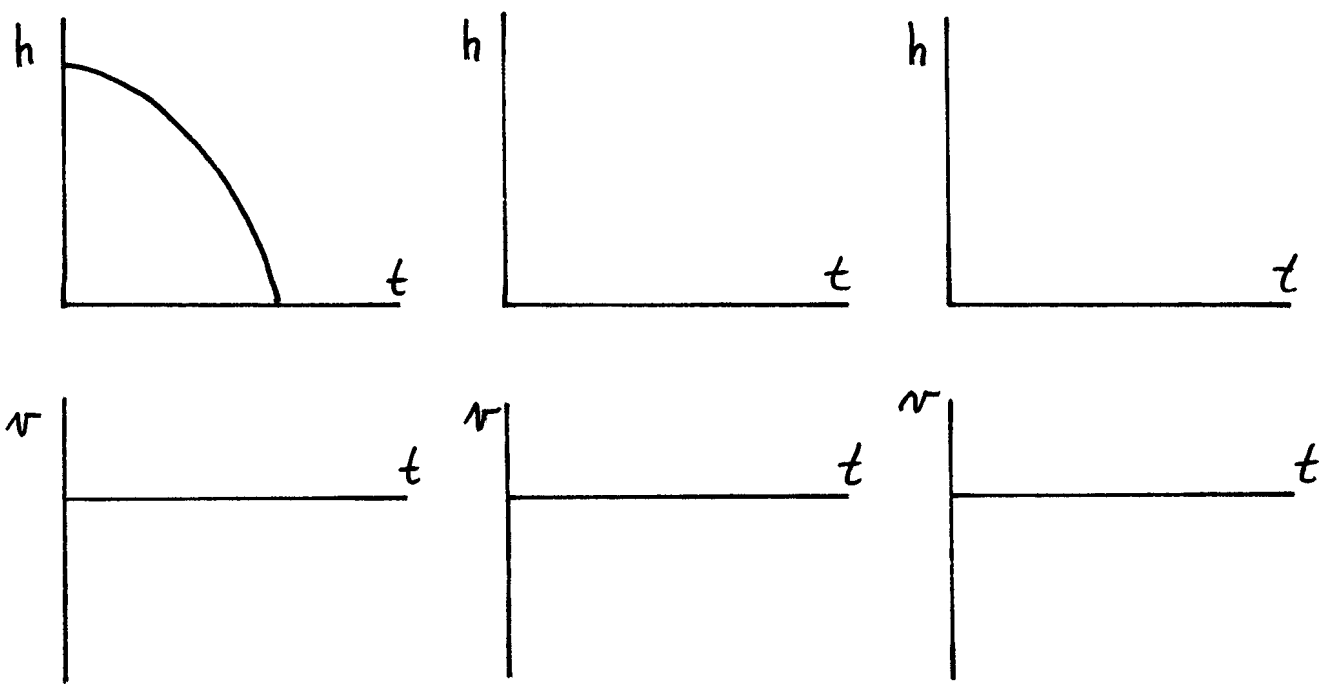
1. A, B, and C are three people standing on a balcony at height h above the ground, each is holding a golf ball. Let t = 0 be the time at which the golf balls leave the hand of each individual.

   A drops hers from rest. Using graph outline (a) below, draw a graph that represents the height h at time t. Draw the velocity versus time graph for this motion.

   Then B tosses his golf ball straight upward. Show how the position versus time and velocity versus time graphs differ from the dropped case by filling in graph outlines in set (b).

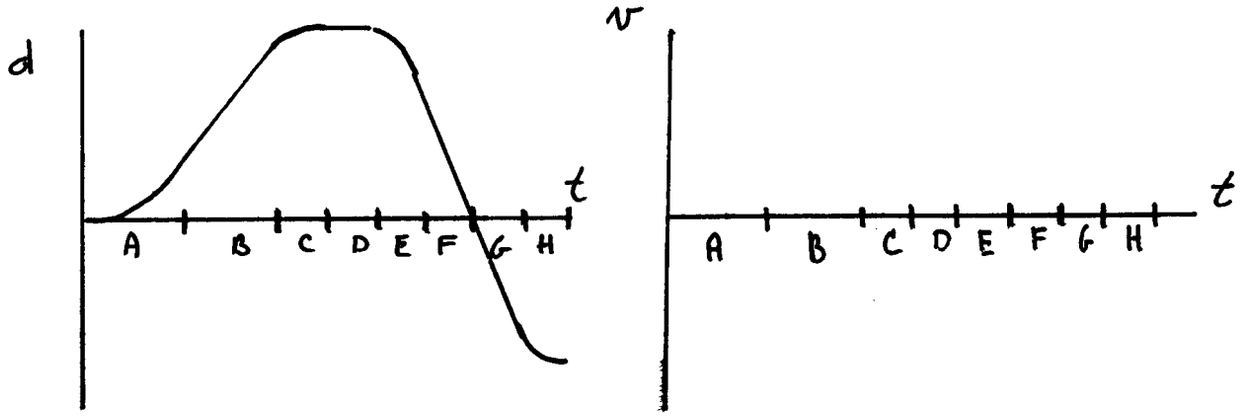
   C throws his golf ball straight down. Again show how this initial velocity affects the motion by plotting two graphs in set (c).

(a) (b) (c)



2. Discuss how the three accelerations versus time graphs compare in the cases above.

3. Sketch the velocity versus time graph corresponding to the distance versus time graph below.

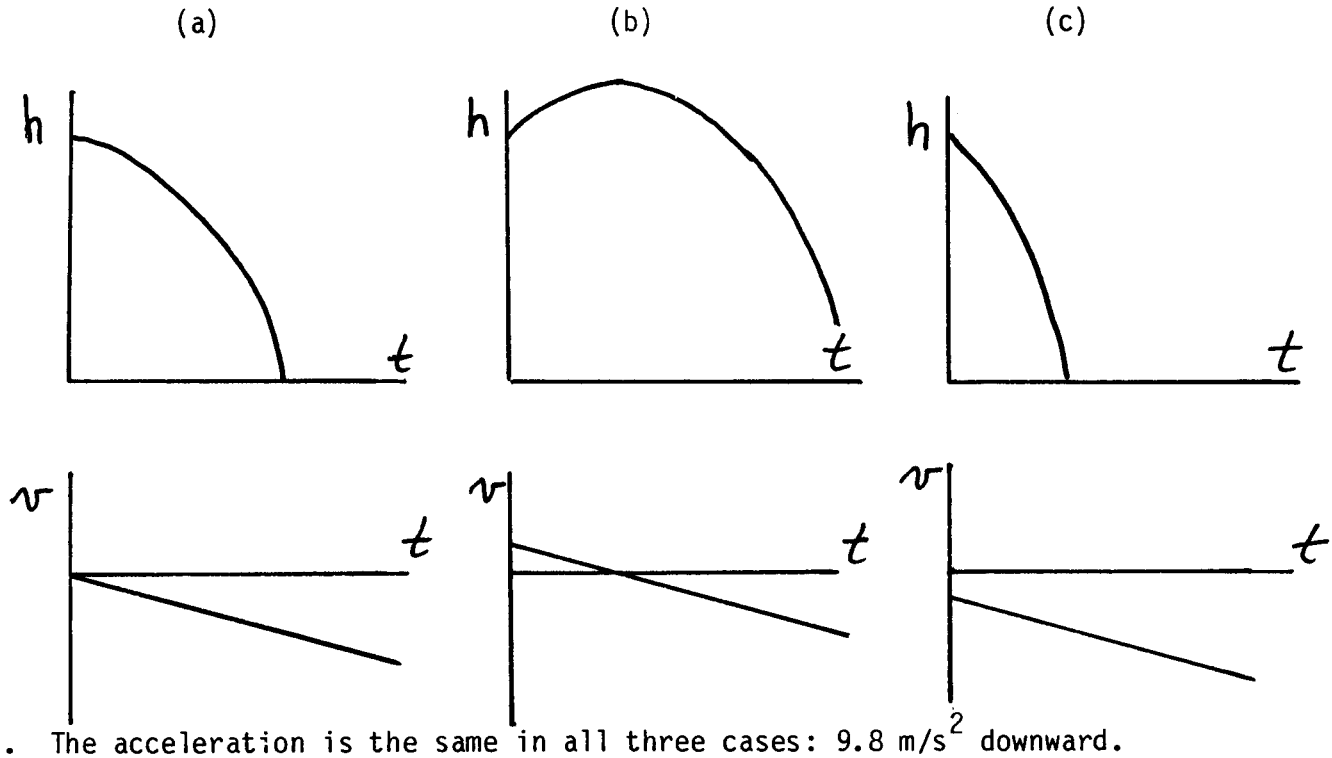


4. At which of the lettered time intervals is there any acceleration, either + or -, occuring?

QUIZ ON GRAPHS WITH DIRECTION NAME OF STUDENT: KEY

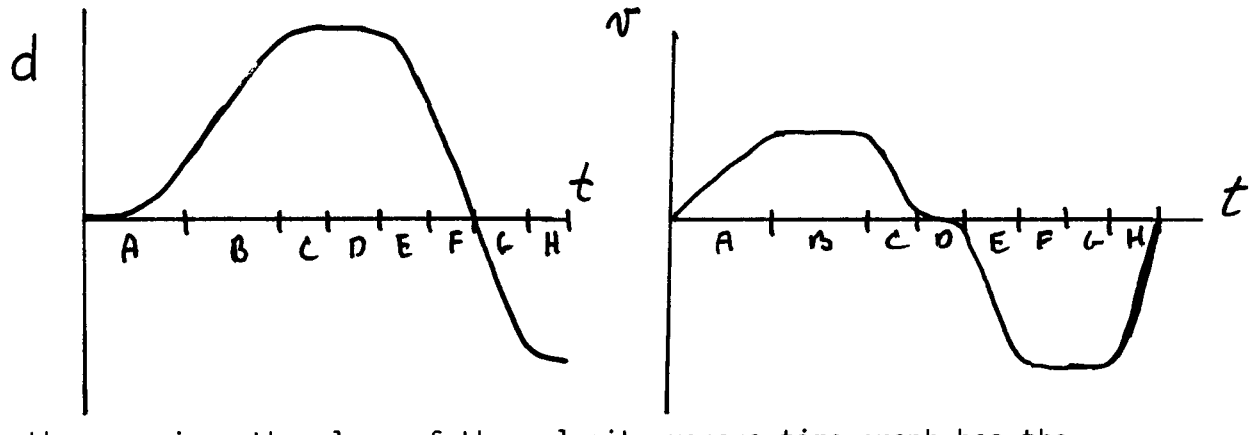
DATE_____ PERIOD: _____

1.



2. The acceleration is the same in all three cases: 9.8 m/s^2 downward. Note that the slopes of the velocity versus time graphs should all be equal. Only the v_i's are different.

3.



4. In these regions the slope of the velocity versus time graph has the following sign: A (+), B (zero), C (-), D(zero), E (-), F(zero), G (+).

V. USEFUL SKILLS

The worksheets which follow are designed to help students learn or practice some of the basic skills needed in physics.

A. Working With Powers of Ten
B. Algebra With Units
C. The Art of Estimation
D. Significant Figures
E. Problem Analysis

A reference handout on the skills of making and interpreting graphs was included in Section III (pages 37 to 41).

There are numerous other sources of help and information about needed mathematics skills. You may already have some in your textbook appendix, workbook, or teacher's guide. Listed below are several you might find useful.

For students:

Programmed Mathematics Reviews, by H.R. Crane

Good self-help for poorly-prepared students in five different areas:

1) Algebra.
2) Powers of Ten.
3) Angles and Triangles.
4) Trigonometry.
5) Vectors.

These can be ordered from AAPT (see AAPT Products Brochure). They are $0.75 a piece or $3.50 for the set.

The Physics Problem Problem Solver, Research and Education Association, 342 Madison Avenue, NY 10017.

Sample problems not only from the basic skills area but from topics throughout the courses.

For the teacher:

Used Math, by Clifford E. Swartz. Prentice-Hall, NJ, 1973
The first three or four chapters contain an admirably lucid discussion of the basic skills. Others chapters could prove useful later on in the course.

Student Patterns of Thinking and Reasoning, by Arnold B. Arons
A 3-part series of articles in The Physics Teacher magazine, the issues of December 1983, January and February 1984. They suggest good ways to help students move from mere manipulation of formulae to real comprehension of mathematical relationships.

Errors, Discrepancies, and the Nature of Physics, by Dana Roberts
An article in the March 1983 issue of The Physics Teacher which stresses the philosophical role uncertainty plays in physics, and how to get this across to students, especially in their laboratory work.

USEFUL SKILLS

A. WORKING WITH POWERS OF TEN

I. Definitions:

$10^0 = 1$ $\quad 10^1 = 10$ $\quad 10^2 = 10 \times 10 = 100$ $\quad 10^{-1} = 1/10 = 0.1$

$10^{-n} = 1/10^n$ $\quad 1/10^{-n} = 10^n$ $\quad 10^{1/2} = \sqrt{10}$

Practice problems: (answers to all problems are given at the end)

1. $10^3 =$ _____ 2. $10^{-3} =$ _____ 3. $1/10^2 =$ _____

II. Multiplication and Division with number expressed in powers of ten:

Rules: $10^n \times 10^m = 10^{n+m}$ $\quad 10^n/10^m = 10^{n-m}$

Examples: $(3 \times 10^2) \times (2 \times 10^5) = 6 \times 10^7$

$(3 \times 10^2)/(2 \times 10^5) = 3/2 \times 10^{2-5} = 1.5 \times 10^{-3}$

Practice problems:

4. $(6 \times 10^9) \times (2 \times 10^{-7}) =$ _____
5. $(6 \times 10^9)/(2 \times 10^5) =$ _____
6. $1/2 \times 10^{-4} \times 7.2 \times 10^4 =$ _____
7. $(3 \times 10^{-2})/(4 \times 10^5) =$ _____

III. Scientific Notation:

Rule: $a \times 10^n = 10a \times 10^{n-1} = 100a \times 10^{n-2} =$
$0.1a \times 10^{n+1} = 0.01a \times 10^{n+2}$

In English: when a is multiplied by 10^m, its power of 10 must be decreased by m to compensate. Conversely, if a is divided by 10^m, its power of ten must be increased by m to compensate.

Examples: $361 \times 10^3 = 36.1 \times 10^4 = 3.61 \times 10^5$
$0.00361 = 0.0361 \times 10^{-1} = 0.361 \times 10^{-2} = 3.61 \times 10^{-3}$

The final form of each of the above examples, with only one integer to the left of the decimal point, is in the form called scientific notation. One of the advantages of this form is that all "place-holding" zeros are eliminated.

Further examples: $61{,}200 = 6.12 \times 10^4$ $\quad$ $0.0612 = 6.12 \times 10^{-2}$

Practice problems: rewrite in scientific notation:

8. $505 \times 10^2 =$ _____
9. $0.505 \times 10^{-2} =$ _____
10. $790 \times 10^4 =$ _____
11. $790 \times 10^{-5} =$ _____

IV. <u>Adding and Subtracting with number expressed in powers of ten</u>:

Rule: Numbers with different powers of ten must be converted to the same power of ten before they can be added or subtracted.

Examples: $5 \times 10^2 + 6.0 \times 10^3 = 0.5 \times 10^3 + 6.0 \times 10^3$
$= 6.5 \times 10^3$

$7.90 \times 10^{-2} - 9.0 \times 10^{-4} = 7.90 \times 10^{-2} - 0.09 \times 10^{-2}$
$= 7.81 \times 10^{-2}$

Practice problems:

12. $4.5 \times 10^3 + 2.04 \times 10^4 =$ _____
13. $8 \times 10^{10} - 4.0 \times 10^{11} =$ _____
14. $790 \times 10^2 - 0.505 \times 10^5 =$ _____

V. Powers and Roots with number expressed in powers of ten:

Rule: $(10^n)^m = 10^{nxm}$ $\quad (a \times 10^n)^m = a^m \times 10^{nxm}$

Examples: $(2 \times 10^3)^2 = 4 \times 10^6$ $\quad (2 \times 10^{-3})^{-2} = 1/4 \times 10^6$

$(3 \times 10^{-2})^3 = 27 \times 10^{-6}$

$(8.1 \times 10^5)^{1/2} = 8.1 \times 10^5 = 81 \times 10^4 = 9 \times 10^2$

Practice problems:

15. $(4 \times 10^{-1})^{-3}$ = _____
16. $(1.1 \times 10^4)^2$ = _____
17. $(1.6 \times 10^3)^{1/2}$ = _____
18. $(80 \times 10^2)^{1/3}$ = _____

VI. Orders of Magnitude:

Definition: The order of magnitude of a number is the power of ten it is nearest to.

Examples:	Numbers:	3.1×10^3	7.6×10^3	7.1×10^{-4}	0.00036
Order of magnitude:		10^3	10^4	10^{-3}	10^{-4}
Or simply		3	4	-3	-4

Find the order of magnitude of the product: 274.2 x 847 _____

274.2 x 847 is about $3 \times 10^2 \times 8 \times 10^2 = 24 \times 10^4$

Order of magnitude = 10^5

The same result is obtained from $10^2 \times 10^3$. You don't need to completely multiply the numbers to get an order of magnitude. (or completely divide, either)

Practice problems: find the orders of magnitude

19. 5,497,568 _____
20. 0.0067543 _____
21. 99 x 187 _____
22. 95,791/7796 _____

Answers to practice problems:

1. $10 \times 10 \times 10 = 1000$

2. $1/(10 \times 10 \times 10) = 1/1000 = 0.001$

3. $1/100 = 0.01$

4. 12×10^{2}

5. 3×10^{4}

6. $3.6 \times 10^{0} = 3.6$

7. 0.75×10^{-7}

8. 5.05×10^{4}

9. 5.05×10^{-3}

10. 7.9×10^{6}

11. 7.9×10^{-3}

12. 2.49×10^{4}

13. -3.2×10^{11}

14. 2.85×10^{4}

15. $1/64 \times 10^{3}$

16. 1.21×10^{8}

17. $16 \times 10^{2} = 4 \times 10^{1} = 40$

18. $^{3}\ 8 \times 10^{3} = 2 \times 10^{1} = 20$

19. 10^{7}

20. 10^{-2}

21. 10^{4}

22. 10^{1}

USEFUL SKILLS

B. ALGEBRA WITH UNITS

There are several important differences between the way calculations are done in algebra classes and in physics. In algebra you usually start with, "Let x equal the unknown quantity." In physics the quantity will have its own special symbol: d (or sometimes s) for position or distance, v for speed or velocity, t for time, r for radial distance, and so on. About the only time x is used is to indicate a horizontal distance.

More importantly, most quantities have units attached to them and in physics they stay attached. When you solve for an unknown quantity, you must solve not only for the number, but also for the appropriate units. Units must be multiplied and divided along with the numbers. You should not grinding out the calculation, and then sticking feet or mi/hr or whatever unit you need on your answer. This requirement is often called dimensional analysis or the factor-label method.

This will seem like busywork for simple problems, but you should acquire the habit if you are to survive as the problems become more complex. There is also a very useful byproduct: units serve as a check on your algebra. Example: Suppose you wrote down the relationship between distance, speed, and time this way: d = v/t. Then the units of d would be the units of v divided by the units of t: m/s over s = m/s2. But that's an acceleration, not a distance unit, so you know you've goofed! It tells you to go back and recheck your equation and/or your algebra.

Although the value of a measured quantity always has a unit attached to it, the algebraic symbol for that quantity should never have a unit attached. You should write 5 meters, 2 seconds, or 9.8 m/s^2, but NEVER write d meters, t seconds, v m/s, or a m/s^2. It is just d, t, v, or a. Look what happens if you do:

A drag racer accelerates from 0 to 60 mi/hr in 5 seconds. Find the average acceleration.

$$a(m/s^2) = \Delta v / \Delta t = 60 \text{ mi/hr} \times 1/5 \text{ s} = 12 \text{ mi/hr-s}$$

Change miles to meters and hours to seconds:

$$a(m/s^2) = 12 \text{ mi/hr-s} \times 1 \text{ km}/0.62 \text{ mi} \times 10^3 \text{ m/km} \times 1 \text{ hr}/ 3.6 \times 10^3 \text{ s}$$

Cancel any quantities that are identical in numerator and denominator (mi, km, hr, 10^3) and collect terms.

$$a\ (m/s^2) = 12/(3.6 \times 0.62)(m/x2) = 5.4\ m/s^2$$

Divide both sides by m/s^2, and the result is a = 5.4! But that is just the kind of answer you would get if you didn't use units at all! So leave the units off the symbols.

Practice problems: Be sure your answers come out in the right units.

1. One mi/hr equals how many m/s? (This is a handy conversion to know.)

2. What change of velocity would you expect to occur in 0.21 second if the acceleration is constant at 12 m/s^2?

3. How many minutes does it take to drive 11 miles at 55 mi/hr?

4. With constant acceleration a, the time required to go a distance d is given by the equation :

$$t = \sqrt{2d/a}$$

Prove that the right hand side of the equation reduces to the dimension of time.

Answers: 1. 1 mi/hr = 0.45 m/s 2. v = 2.5 m/s 3. t = 12 min.
4. The dimension for $\sqrt{d/a}$ is $\sqrt{(\text{distance} \times \text{time}^2)/\text{distance}}$ = time.

Example: $\sqrt{m/(m/s^2)} = \sqrt{(m \times s^2)/m} = s$

USEFUL SKILLS

C. THE ART OF ESTIMATION - FERMI QUESTIONS

It has been said that a physicist should never do a problem until he or she already knows the answer. Of course, that doesn't mean an exact answer, but refers to the habit of doing a "ball park" calculation for an answer by doing a swift and simple calculation with approximate numbers.

Example: Find the length of a light year (the distance light travels in a year) in meters.
Actual data: Speed of light (c) = 2.9979×10^8 m/s
Seconds in a year: 365.25 days x 8.640×10^4 s/day

Estimation: 1 light year is about:
3×10^8 m/s x 3×10^2 days/yr x 10^5 s/day = 9×10^{15} m.

Actual calculation to 5 significant figures:
1 light year = 9.4607×10^{15} meters.

Enrico Fermi, a Nobel Prize winning physicist, invented the physics game call "Fermi Questions." The object is to calculate the order of magnitude of some outrageous problem without knowing or looking up any of the data. One of his famous questions is, "How many red-headed piano tuners are there in the city of Chicago?"

Now that sounds impossible to guess, but here's how you go about it. First, estimate how many households there are, how many of these have pianos, how many tuners are needed, and what percent are red-headed. Carry through calculation with no more than one integer along with the powers of ten, then decide whether your answer is closer to 1, 10, 10^2, 10^3, or 10^4. Fermi question contests are now held all over the country as part of Physics Olympics competition.

Example: How many words are there in the Encyclopedia Britannica?
20 volumes x 10^3 page/volume x 10^3 words/page = 10^7 words.

Practice problems:

1. How many Ping-Pong balls would it take to completely fill your physics classroom?

2. How many blades of grass are growing on your school football field?

3. If all the sticks of gun chewed in the United States in one day were laid end to end, how far would they reach?

Compare your answers with those of your classmates. Were your assumptions wildly different?

USEFUL SKILLS

D. SIGNIFICANT FIGURES

No measured quantity is ever exact. That is no measured quantity is known to an infinite number of decimal points. At some stage in a measurement one can no longer count whole units but must make an estimate of fractional units. Thus the last digit in a measurement represents the measurer's best guess. It is uncertain.

The simplest way to indicate how much uncertainty a number has is through the number of significant figures (SF).

When you express a number in SF, you are saying that you are sure of every digit except the last one.

a. Counting Significant Figures

When is a zero significant? Study the examples and find the rule. All of the following have 3 SF (this 3 is a counting number and therefore exact):

3.03 303 0.0303 30300 (All can be written 3.03 x some power of ten.)

3.00 30.0 0.0300 (What reason could there be for the final zero?)

All these have 2 SF: 3.0 0.0030 3.0×10^{-3}

These have 1 SF: 3 0.3 0.003

Since the following three numbers are not in scientific notation, the number of SF are ambiguous (rigorously only 1, but possibly 2 are intended):

30 300 3000

Practice problems: how many SF are in each of the following numbers? Answer with ? if ambiguous.

1.	5005 SF = ___	5050 SF = ___	5500 SF = ___	5000 SF = ___
	0.5005 SF = ___	0.5050 SF = ___	0.5500 SF = ___	0.5000 SF = ___
	0.0005 SF = ___	0.0505 SF = ___	0.0550 SF = ___	0.00050 SF = ___

b. Multiplying and Dividing Numbers using Significant Figures:

Study the examples and deduce the rule:

3 SF x 2 SF has 2 SF ($201 \times 2.0 = 4.0 \times 10^2$)
4 SF x 1 SF has 1 SF ($2.011 \times 0.3 = 0.6$)
3 SF / 3 SF has 3 SF ($201/2.01 = 1.00 \times 10^2$)
2 SF / 4 SF has 2 SF ($2.1/1.0533 = 2.0$)

Rule: The result of multiplying or dividing numbers with significant figures can have no more SF than the least significant number in the calculation.

Practice Problems:

2. $3.5 \times 0.007 =$ _____

3. $9.00 \times 6.06 \times 10 =$ _____

4. $21650/5.0 =$ _____

5. The speed of light has been measured as 2.99792458×10^8 meters/second. If you were asked to find how far light travels in exactly 2 seconds, how many SF would you be allowed in your answer?

c. Adding and Subtracting Numbers using Significant Figures:

Rule: Convert all numbers to be added or subtracted to the same power of ten. The answer may have no more decimal places than the number which has the fewest number of decimal places after the conversion.

Examples:

$$\begin{array}{r} 2.106 \times 10^{2} \\ 0.07 \times 10^{2} \\ 58.1 \times 10^{2} \\ \hline 60.3 \times 10^{2} \end{array} \qquad \begin{array}{r} 58.1 \times 10^{-1} \\ -1.07 \times 10^{-1} \\ \hline 57.0 \times 10^{-1} \end{array}$$

Practice problems:

6. $5 \times 10^{4} + 6.0 \times 10^{5} =$ _____

7. $8 \times 10^{2} - 4 \times 10^{3} =$ _____

8. $2.9 \times 10^{5} + 3.5 \times 10^{2} =$ _____

d. Powers and Roots of Numbers using Significant Figures:

Rule: A power or root of a number has the same number of SF as the number itself.

Examples: $\sqrt{121} = 11.0$ $\qquad$ $11^{2} = 120$

Practice Problems:

9. $4.0^{2} =$ _____

10. $\sqrt[3]{27} =$ _____

Answers to practice problems:

1. First Row: 4, ?, ?, ? Second Row: all 4 Third Row: 1, 3, 3, 2.

2. 2.4 3. 5.45×10^{-2} 4. 4.3×10^{3} 5. ten

6. 6.5×10^{5} 7. -3×10^{3} 8. 2.9×10^{5} 9. 16

10. 3.0

USEFUL SKILLS

E. PROBLEM ANALYSIS

Word problems! If you dread them, you have lots of company. Yet most of the problems you're asked to do in physics are not the "plug and chug" variety -- at least not until you've analyzed the word part well enough to write down an equation to plug into.

Perhaps what you need is a set of steps to follow each time you encounter a word problem. If the steps work well for you a few times, perhaps your dread will soon disappear.

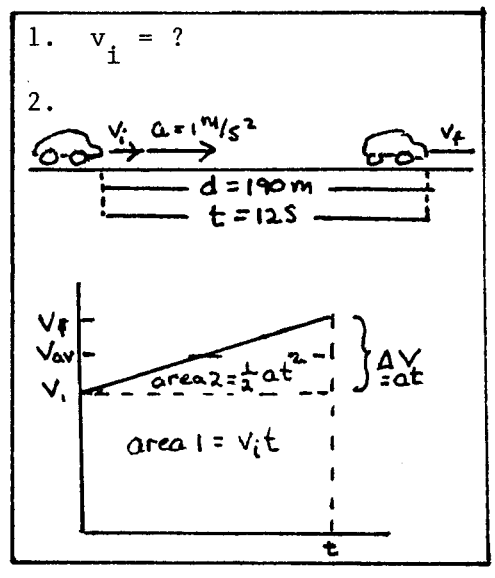
Here is a intimidating problem from the PSSC textbook, involving motion with constant acceleration:

> A car, initially travelling at uniform velocity, accelerates at the rate of 1.0 m/s for a period of 12 seconds. If the car traveled 190 meters during this 12-second period, what was the velocity of the car when it started to accelerate?

Let's try the steps on it and see what happens.

Step 1. Read the problem carefully, several times if necessary, to discover what it is asking you to find. Write down the algebraic symbol for this unknown and follow it with a question mark.

Step 2. Reread the problem to get a mental picture of the situation it poses. Then draw a sketch and/or graph to make the picture concrete. Label your drawing with whatever information the problem supplies.



Step 3. What relationships can you think of between the unknown and the information given? Jot down the algebraic symbols for the knowns next to the unknown to see if an equation will come to mind.

Step 4. When you have the right equation, do the algebra first before you plug anything into it.

Step 5. Put in the numbers <u>and the units</u> and chug away. But be sure to check your answer two ways before you finish:

(1) Are the <u>units</u> right?

(2) Is the answer <u>reasonable?</u>

<u>3.</u> v_i v_f d t a

There are many relationships; which to use? Maybe areas under the v-t graph?

total area = d

area 1 = $v_i t$

area 2 = at x t/2 = $at^2/2$

$d = v_i t + at^2/2$ Aha!

<u>4.</u> Algebra first:

$v_i t = d - at^2/2$

$v_i = d/t - at/2$

$= \frac{190\ m}{12\ s} - \frac{1\ m}{s^2} \times 6\ s$

$= (15.8 - 6)m/s = 9.8m/s$

<u>5.</u> m/s is an OK unit for v_i, and 9.8 m/s is neither too big nor too small to be out of line.

VI. HELPING SPECIAL STUDENTS

A well-taught physics course has enough content to interest and challenge most students. But the occasional brilliant student who can effortlessly outstrip the others and the low ability student who is soon left behind both need special attention.

After you have spotted an unusally able student (based on your observations and backed up by previous records) you must make a particular effort to communicate directly with the student. Contrary to general belief, such students are not really better off if left to their own devices. There will be more progress under your guidance and with your cooperation than without it. In deciding that a student is really talented, however, don't be misled by a large technical vocabulary. Students, especially hobbyists, often pick up a glib jargon with little real understanding. Try to find out what the student really knows.

A student may be considered disadvantaged for a number of reasons, any of which may impede learning. The impediment may be a language or social problem, a physical handicap, or low native ability. This last problem is tricky; intelligence is often masked by other factors. Sometimes it's just immaturity. A student who resembles a slow learner should often be handled instead as a slow starter. Try to expect success. The result may surprise the student as much as you.

Some of the best methods of dealing with the extreme students are:

1. It is well known that the teacher's enthusiasm, evident concern and interest are important in teaching all students. For the unusual student this concern is best shown in your personal contacts. In both cases you must find out the level at which the student really is before you can help. The laboratory is a good place to get acquainted. An occasional supervised work period in class will also give you a chance to make one-on-one contacts. Get to know your students as individuals.

2. Make your homework assignments with both types of student in mind. Start each set with a few simple questions and problems that are well covered in the text. Then include a couple of questions that demand a little more enterprise. They may be problems with two or three steps, or applications that are not specifically spelled out in the book. Finally add two optional problems of a more difficult nature. Students are not required to do these, but many of the bright ones will like the mind-stretchers. In discussing homework be sure to spend the bulk of the time on the simpler, more basic questions. To keep the bright kids from monopolizing your class time with questions about the optional problems, post full solutions and answers to these on your bulletin board. If your own textbook and teacher's guide don't offer the variety of problems and solutions you need, seek help from your buddy, librarian, science supervisor, or local college physics department.

3. Make individual projects a part of your course. The students of poor ability will accomplish much more working on projects that interest them then by dozing in a formal class. The brilliant students will find challenging topics that fit their own ability. What kind of projects? Both written and experimental projects are worthwhile. Many laboratory experiments can be expanded to make good projects by devising alternate procedures or by investigating sidelight. Some laboratory manuals make suggestions. The history of physics, if it concentrates on physics, can be quite exciting. Galileo's experiment on balls rolling down an incline, timed by a water clock, is describe in the Project Physics laboratory manual and fits well with work in kinematics. Another way to find a good project idea is to open a textbook at random, identify a key idea and then consider, "How do they know that?" or "What if this other factor is changed?" or "Does this same thing apply to other cases?"

4. Try to provide classroom reference materials at a variety of levels and attractive to a wide range of interests. Your librarian can help. Make time for students to use them.

5. Keep the laboratory open at stated times during and after school and make it attractive for students to use the opportunity. Give the bright students freedom to do investigative experiments (as long as you know and approve their plans) while you sit down with the disadvantaged student who is groping. Keep the pressure low and try to build self-confidence.

6. Encourage students to help each other. Both bright tutors and disadvantaged tutees will profit.

7. The Physics Olympics offer a splendid opportunity for both talented and slow students. Some of the most popular events are described in your supplementary materials. (e.g. Egg Drop, Paper Tower, and Bridge Building). These can be done within your own classroom as special activities. If there is a regional Olympics held in your area, consider entering a team from your class to compete against other schools, or at least send some of your students to observe so they can return and spread the gospel for next year.

Some suggestions especially for the very bright students

1. Self-pacing. Brilliant students can master the subject matter much faster than others. If forced into the lockstep of class routine they can be quite a burden to both teacher and classmates; their interests and questions go far beyond anyone else's level. A teacher must be very careful to avoid allowing such very bright students to monopolize class time.

There is no reason to hold them back. One way to handle it is to give them a college level text and allow them to work together or alone in the back of the room, the library, or some other supervised setting. However, they should still be required to do the laboratory work and tests with their class. If you can find someone adequately prepared to guide one or more of these superstars, they should be encouraged to prepare for the Advanced Placement examinatin in physics.

In one extreme of self-pacing, the individual worked through a college text in one semester, consulted with the teacher once a week, took the tests designed for the textbook and wound up with a brilliant success and eventually a Ph.D. in astrophysics.

2. There are a number of contests that reward outstandingly able students. Watch in the fall for announcements from Science Fairs, NASA, AAPT, NSTA and other likely sponsors. The National or State Bridge Building Contest rules can be requested from the address given in the Physics Olympics materials. You must be an enthusiastic promotor, well ahead of time, to motivate worthy entries.

3. If you know in advance that you're going to have to be out of school for a day, tutor your brightest students to teach your classes. The official substitute, who probably knows no physics and is fearful at the prospect of just sitting on the lid for the day will be very happy to stay in the back of the class while knowledgeable students do the actual teaching. The bright ones love the assignment, and if you have chosen them wisely, the others will also like the experience.

4. Have some of the best students help you set up the laboratory activities and demonstrations for the following day. Make sure, however, that these helpers really want the job; many would regard it as just another chore.

5. If there is a college or university in your community, help very bright students to make contact with a member of the physics faculty. Physics departments are usually interested in attracting able students, and may make it possible for the student to take a college course or prepare a sophisticated project under the professor's tutelage.

Some suggestions especially for the disadvantaged students

1. Accept this student at his or her own level. You should try to arrange your class routine so that lots of individual help can be given tailored to the student's problems.

2. Be very gentle in telling a disadvantaged student that he or she is wrong.

3. Educationally disadvantaged students need extra help in basic mathematics and reading skills. It's not easy to be a mathematics and reading teacher as well as a physics teacher, but in some cases it's necessary. Perhaps a colleague who teaches English or mathematics can help.

4. Give these students special practice in taking tests. Provide the sort of test items that will make them more familiar with not only your tests, but standardized tests. There's a lot to being "test-wise," and a little success can change an individual student's entire outlook.

SECTION VII. DYNAMICS AND BEYOND

What do you do and where do you go from here? Ahead lies Newtonian dynamics with its three basic laws of motion, the great conservation principles of momentum and energy, and the universal law of gravitation. This is the heartland of classical physics. It is the foundation needed to understand many of the practical and theoretical applications that abound in our daily lives. But glamorous it isn't. It can be long and arduous and abstract. To keep students from discouragement or boredom, you need to provide them with a variety of learning techniques -- not just lectures, worksheets, and homework problems, though these are necessary and helpful.

Now is the time to increase their opportunities for hands-on experience with physical phenonema. Before anyone mentions momentum or its conservation, let students find out what happens when a brick is dropped on a moving cart. Let them explore collisions between things that stick together, things that bounce off each other, things of the same or different mass that hit head-on or hit off center. Let them play with pendulums and stretching strings. There are dozens of good laboratory activities that are designed for making measurements and reaching conclusions, but these are sometimes better when they follow earlier opportunities to just "mess around".

Spice up your daily classes with a variety of activities including optional activities, incentives, an occasional good physics film, contests, field trips. The local amusement park is a splendid place to observe dynamics on a large scale, particularly centripetal force, gravitational potential energy, and the conversion of potential into kinetic energy and back again. Make a trip to the park the incentive for keeping noses to the grindstone for a while.

Designing and building a Rube Goldberg device appeals to some students and makes a great project to illustrate energy transfers in a complicated system. Others who are more oriented to the humanities might be turned loose to explore the historical background of physics, whether its ancient Greek roots or its rebirth during the Renaissance. The dramatis personnae of the Scientific Revolution, from Copernicus to Newton himself, are interesting not only for their mighty contributions to progress but for their quirky personalities. They make for good reading.

Try out some Physics Olympics contests or invent some of your own. Rewards for winners might be certificates entitling them to one or more days of homework exemption.

It will be important for students to learn new precise meanings for some familiar but imprecise words. They come to physics thinking that conservation, for instance, means being careful not to waste or destroy a natural resource. It takes a bit of effort to convey the quite different meaning of a conservation law. (A conserved quantity, in science, is one whose total amount remains constant in any closed system.)

Force, inertia, field, impuse, work, energy -- all take on special meanings in physics from the way they are related and how they are measured. Students will have intuitive ideas of all of these concepts, but they will need help to sharpen and clarify and put them to use. Energy, for example, is a very abstract concept, impossible to define in general, but easy to measure in some of its forms.

Beyond dynamics you'll probably plunge next into electricity and magnetism. By now you'll be an old hand at planning hands-on student involvement, and this is another area of physics where there are lots of possibilities. Do all the laboratory activities that you have the equipment for, but add some extremely simple ones when you begin electric circuits. Many of your students have never completed one except by pushing a button or plugging an appliance into an outlet. They have never stripped a wire or repaired an extension cord. If you give them flashlight batteries, flashlight bulbs, and hook-up wire, some of them will have to experiment for quite a while to get the bulbs to light. They don't know the difference between amps and volts, they've never read a circuit diagram, and are quite apt to damage meters and blow fuses unless rigorously instructed.

If it's possible that you yourself fall into this category, don't be embarrassed to confess it to someone who can coach you in the simple basics. Inexperienced kids seem to get a big kick out of making a lamp light or a bell ring that they've hooked up from scratch, and you probably will too! You won't find laboratory activities written up for these preliminary activities in circuitry, but you can write your own.

The study of electricity usually begins with electrostatics, during which students observe some of the evidence that leads to the two-charge model of electricity and matter. Be sure to stress induction, because students are bound to see examples of like charges attracting and have their faith in scientific dogma badly shaken. (Induction provides the model to explain how a charged body attracts a neutral object or even a body charged alike.) Later when you get to magnetism they will not be so shocked when they find two north poles attracting, if one is weaker than the other.

One more tip on magnetism: don't get involved with iron fillings. They're incredibly messy to deal with. Tiny compasses are much better for mapping magnetic fields, since they indicate the direction at any point on a field line. Incidentally, you need to know which way true north is in your laboratory and classroom so compasses can be checked. They are easily reversed so that the blue end or the one with an arrow on it is not necessarily the pointer end. The end that seeks true north in the earth's field is by definition the end that points in the direction of any other magnetic field, and is itself a north pole.

The study of the behavior of light, waves, and sound can be done almost entirely through the laboratory activities. If you have ripple tanks be sure to use them. They make wave behavior both fascinating and beautiful. There is a series of super-8 film loops of ripple tank phenomena that slow down the motion and make it easier for students to understand. These may also be available in video cassette form. Write to EDC Distribution Center, 39 Chapel St., Newton, MA 02160, for their catalogue.

We could go on and on and on; every experienced physics teacher is eager to share some cherished tricks of the trade. But you are certainly going to acquire tricks of your own and begin to develop your own teaching materials. Our hope is that you've become accustomed to -- even addicted to -- the phenomenological approach that we have been suggesting in this kit, and that you'll continue to find ways to involve your students directly in the learning process.

APPENDIX A RESOURCES FOR DYNAMICS AND BEYOND

PRISM Handbook

This is a complete syllabus for a high school physics course, especially designed for the new or underprepared physics teacher by the Iowa Department of Public Instruction. It lists appropriate demonstrations, films, video cassettes, computer programs, and practicle applications for each topic. Recently published in draft form, it is available at no charge (at least for now). Write to Jack Gerlovich, Iowa State Science Consultant, Grimes State Office Building, Des Moines, IA 50319.

Phenomenal Physics, Clifford Swartz, John Wiley & Sons, 1980

The Various Language, Arnold Arons, Oxford University Press, 1977

The Way Things Work, a two-volume encyclopeida of modern technology

Asimov's Biographical Encyclopedia of Science

Demonstration Handbook for Physics, Freier and Anderson. Available from AAPT

Cinescope of Physics, an AAPT Film Resource Book

Astronomy Resources

If there is a large astonomy compenent in your course, as in Project Physics, write to The Astronomical Society of the Pacific, 1290 24th Ave., San Francisco, CA 94122, for a list of their many helpful teaching aids.

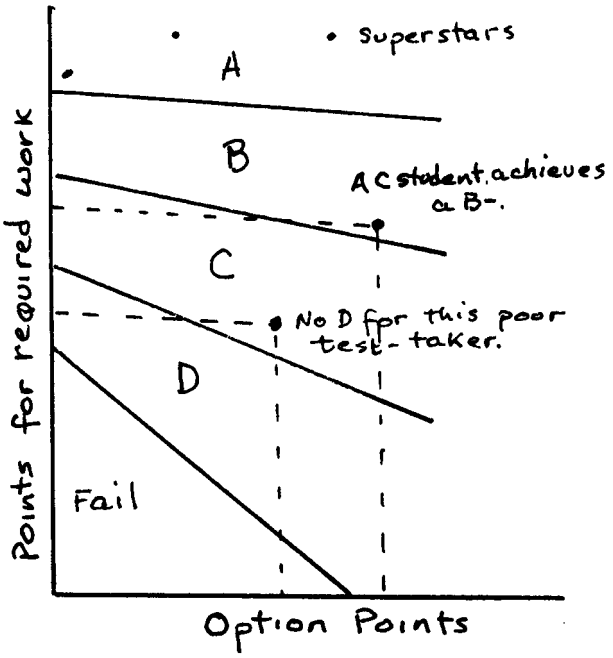
APPENDIX B SOME SAMPLE GRADING SCHEMES FOR A PHYSICS CLASS

1. Two versions of a quarterly grade based on three major components:

a.	Quizzes	30% of grade	b.	Quizzes	50%
	Laboratory	45% of grade		Test	25%
	Examination	25% of grade		Laboratory	25%

2. A two-dimensional scheme that counts points received for optional work separately from points earned from required work. These coordinates yield points on a graph. Then division lines are drawn at different tilts. For the A's the line is almost horizontal, to avoid grade inflation in this range. (You wouldn't want to award an A for a lot of Mickey Mouse projects.)

However, the lines can be made quite steep for the C's and D's giving the poor test takers and the slower learners a chance to use their strengths to make up for their weaknesses. No one needs to fail except the complete non-participant.



APPENDIX C WHAT'S REALLY IMPORTANT TO KNOW ABOUT MEASUREMENT

1. Measurement is never exact. You can count a small number of separate items exactly, but when you measure a length with a ruler, read a dial or scale you are dealing with continuous quantities where there is always a need to estimate at the two end points. Even when you use a digital watch to time an event you are still estimating. You can count accurately to the nearest whole number of millimeters or hundredth seconds or whatever, but that last digit is just a best guess. Significant figures in measurement are the counted ones your're sure of, plus your best estimate of the final one.

2. The accepted value of a measured quantity isn't cast in stone either. An accepted value just represents agreement among the experts on the best value obtained so far. Take the speed of light, for instance: 2.997924590 x 108 m/s, as of about 1980. Though that's pretty precise-- lots of significant figures with one or more added or changed every so often -- it still isn't absolutely accurate and never can be. The last digit is still just a best estimate. For most calculations we round the speed of light off to a manageable 3.00 x 108 m/s -- and you notice that the last digit here is still uncertain.

3. How uncertain? Significant figures don't tell you much except that the last digit could be anything. A more informative way to say something about the uncertainty involves some analysis of the measurements. Usually it is done by finding the mean of many measured values -- averaging the results from all students in a class, for example -- and noting how far from the average the individual values stray.

Let's say you've completed an experiment to measure the acceleration due to gravity in your school, and the students pool and average their values. The result could come out looking something like this:

$$g = 9.70 +/- 0.15 \text{ m/s}^2$$

Interpreted, that means that the true value of g has a better than fifty-fifty chance of lying between 9.55 and 9.85 m/s2. Not that it does lie there mind you, but the probability that it does is greater than that it falls outside those limits. If you ever took a typical teacher training course in statistics, this may awake some echoes.

The plus-or-minus quantity is obtained mathematically by a choice of methods. It could represent the range, the average deviation, or the standard deviation -- each having a different definition and way of interpreting probabilities. It is often expressed as a percentage rather than a number. You've heard the terms signal and noise? The mean is the signal you get from a measurement, while the plus-minus quantity is the noise (or measure of uncertainty) surrounding the signal.

You'll find a good discussion of uncertainty measures in Used Math, a reference book by C.E. Swartz, or other physics reference books. Don't feel you must teach these techniques to high school students, however. It is perhaps enough that they learn to appreciate the concept of uncertainty.

4. Experimental error. The "plus-or-minus" factor mentioned in the last paragraph is sometimes called experimental error, implying that if you were only more careful you could be certain of your results. Not true, of course, because the necessity to estimate end points is always present. Still, experimenters want to minimize uncertainty as much as possible, and averaging many measurements is one way to do this.

5. Measurement = Number plus Unit! Without units measurements have no meaning. Students come to you after years of math in which little or no attention is paid either to units or to significant figures. You will probably have a tough time getting them to include the units in all their calculations and to express answers in an appropriate number of significant figures. They'll catch on, though, if you test for it!

It's OK to make up units (like time measured in ticks on a ticker tape, or in flashes in a strobe photo). But as a general rule, stick to the international metric system of units (SI). It is in general use practically everywhere in the world except the United States. Mastery of SI is important to students who go on to college science courses, technical careers, or world travel!

Avoid using inches, feet, yards, miles, pounds, and minutes whenever you can, especially in problems where they have to be converted to SI units (meters, kilograms, seconds). It just adds an extra busy-work step; students have more valuable things to do with their time. Don't make them memorize conversion factors; they are easily looked up if necessary. However, they should know how to do conversions by the factor label method, as described in Section V on useful skills.

You'll encounter only three of the fundamental SI units in your study of kinematics: those for length (meter), time (seconds), and mass (kilogram). There are also three more units derived from length and time that students must master in this unit: m/s (velocity); m/s2 (meter per second per second; acceleration); and 1/s (Hertz; frequency). As you go on to dynamics and other topics, there will be a few more fundamental and derived SI units to learn. The chart that follows contains them all, including several that you won't need in elementary physics. The most important ones are starred.

APPENDIX D INTERNATIONAL SYSTEM OF UNITS (SI)

	FUNDAMENTAL QUANTITY	NAME of Base Unit	SYMBOL
1.	length*	meter	m
2.	mass*	kilogram	kg
3.	time*	second	s
4.	electric current	ampere	A
5.	thermodynamic temperature	kelvin degree celsius	K C
6.	amount of substance	mole	mol
7.	luminous intensity	candela	cd

	DERIVED QUANTITY (Mechanics)	NAME	SYMBOL	RELATIONSHIP TO BASE UNITS
1	frequency	hertz	Hz	$1/s$ (s^{-1})
2	area	square meter	m^2	m^2
3	volume	cubic meter	m^3	m^3
4	density	kilogram per cubic meter	kg/m^3	$kg*m^{-3}$
5	velocity	meters per second	m/s	$m*s^{-1}$
6	acceleration	meters per second squared	m/s^2	$m*s^{-2}$
7	force	newton	N	$kg*m*s^{-2}$
8	pressure	pascal	Pa (N/m^2)	$kg*m^{-1}*s^{-2}$
9	energy, work	joule	J $(N*m)$	$kg*m^2*s^{-2}$
10	power	watt	W (J/s)	$kg*m^2*s^{-3}$
11	momentum, impulse	newton second	$N*s$	$kg*m*s^{-1}$

MULTIPLES	PREFIXES	SYMBOLS	SUBMULTIPLES	PREFIXES	SYMBOLS
10	deka	da	10^{-1}	deco	d
10^{2}	hecto	h	10^{-2}	centi*	c
10^{3}	kilo	K	10^{-3}	milli*	m
10^{6}	mega	M	10^{-6}	micro*	
10^{9}	giga	G	10^{-9}	nano*	n
10^{12}	tera	T	10^{-12}	pico	p
			10^{-15}	femto	f
			10^{-18}	atto	a

APPENDIX E METRIC MADNESS

(From the Arizona Science Teachers' Newsletter, October 1978)

If 10^{-6} phones equals 1 microphone, what does 10^{-2} pedes equal? Try out your metric IQ!

1 10^{-1} mate =
2 10^{-3} cans =
3 2×10^{2} withits =
4 10^{1} dents =
5 10^{-9} Nanettes =
6 2×10^{3} mockingbirds =
7 10^{-3} taries =
8 10^{3} monjaros =
9 10^{12} fermis =
10 10^{-6} fish =
11 10^{-6} phones =
12 10^{-2} pedes =
13 10^{6} phones =
14 10^{-12} boos =
15 10^{-18} boys =
16 10^{-2} mental =
17 10^{1} cards =
18 10^{12} buls =
19 2 gorics =
20 10^{9} los =

Answers

1 decimate
2 millican
3 two hectowithit
4 decadent
5 nano Nanette
6 kilomockingbird
7 military
8 kilomonjaro
9 tera fermi
10 microfiche
11 microphone
12 centipede
13 megaphone
14 picoboo
15 attaboy
16 centimental
17 dekacards
18 terabul
19 pairegoric
20 gigolo

APPENDIX F THE AUDIO - VISUAL SCENE

Audio-visual aids are a valuable way to add variety to a physics course. They can not only offer a change of pace but often illustrate phenomena that can't be demonstrated in class. There are films, video-cassettes, slide- and film-strips, film loops, and fancy graphics for the overhead projector or the computer -- so many to choose from that it can be overwhelming. Begin by investigating what your own school system or your local educational film repository has to offer. Probably the best way to check their worth is to order all that are applicable to physics and review them at a leisurely pace. They can be surprisingly helpful to the teacher as a review of concepts even before they are shown to the class.

For a detailed listing of available physics-related films and film loops, there is Cinescope of Physics: An AAPT Film Resource Book, which describes and evaluates 1340 of them produced before 1978. It is available for $8.00 from AAPT; see the Products brochure. More recent films are reviewed reguarly in The Physics Teacher magazine.

When you do show a movie, be sure that it's not just a diversion, but an integral part of the topic under study. Some films are great for introducing a new field; others will demonstrate experiments you couldn't do yourself, or illustrate applications of a theory that are made out in the real world. To keep students alert, you can stop the film every now and then to ask questions, or you can require them to take notes, write a commentary, or pass a quiz question on the film.

If you have a film loop projector available, there are certain super-eight loops that students will willingly use a lot -- the ripple tank ones come to mind -- and others that have never proved very popular. Some mechanics loops that require students to make measurements fall into the latter category. An experienced teacher can help you should you decide to order any.

As or computer programs, which are proliferating -- well, if you're not a computer buff yet, don't worry about it. Their value lies chiefly in helping students drill, or test themselves, and you don't have to have a computer to do that. If the students know more about computers than you do, they may enjoy writing their own programs for physics. On the other hand, if you are into computers you'll find kindred spirits at AAPT Section meetings who will share programs with you and tell you which ones to avoid and which to buy. New software is also evaluated in AAPT publications.

APPENDIX G EQUIPMENT

or

What Is That Thing in My Storeroom?

Apart from a knowledgeable buddy, the best sources of information about mysterious laboratory equipment are the catalogues of its distributors. There you'll find pictures of practically everything they sell, grouped according to the areas of physics to which they apply.

The laboratory programs that accompany recent physics texts are nearly all derived from or influenced by experiments introduced by the PSSC course 25 years ago, so you're apt to find quite a bit of PSSC-type equipment. Or if you are teaching Project Physics you should find some apparatus unique to that course. All of this should be pictured in your own lab manual as well as in commercial catalogues.

If your school has had a long-established physics course, you may discover some pre-PSSC, pre-Project equipment stashed away. It looks old-fashioned because there is no plastic and no electronics, but it tends to be beautifully made. Each set-up is usually designed for just one experiment; modern apparatus often has multiply uses. To identify it you'll need an old catalogue from Sargent Welch, Cenco, or Leybold. Whether or not you use it, now or in the future, treasure it as a valuable antique.