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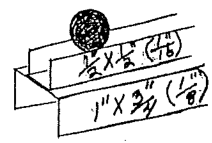
Kinematics and free-fall - Kinematics is the study of the motion of an object <u>without</u> considering any involvement of its mass; the topic, acceleration, is a very important example. For many high school physics students, acceleration is one of the most difficult concepts they encounter all year. That it is so important and usually comes so early in the course, compounds the problem. What they don't need is a stumbling block out of the gate; instead, they need to get off to a good start. So here are a few suggestions that worked for me and might help your students understand acceleration better.

First, when talking about the units that are used for acceleration, stay away from saying "per second squared". For beginners, this only confuses the issue. Instead, say "per second as each second ticks by". Once they understand what's really going on, you can begin using the "per second squared" shortcut.

Along with verbalizing acceleration and the units, present a couple of simple, but very clear, demonstrations involving velocity and acceleration.

(a) A 3/4" dia. steel sphere on an 8 ft. long track. Two pieces of channel aluminum can be purchased at a good hardware store; they can be riveted ("pop") together for strength (1.)

1. 

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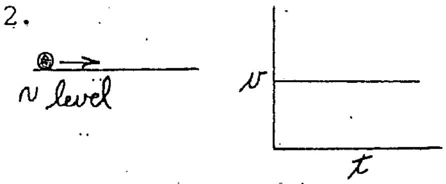

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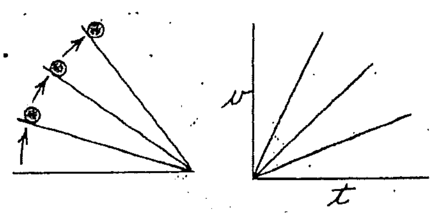

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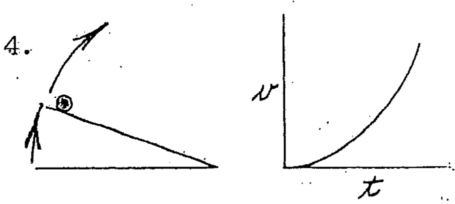


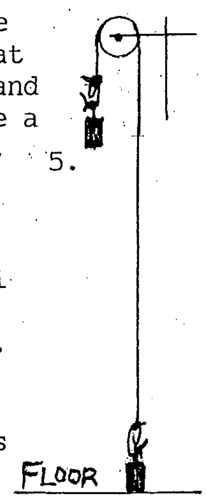
Presentation: Begin with the track nearly level or elevate one end until the rolling sphere reaches a constant velocity (2.). Give the sphere a firm push with your finger. You will note by sight and sound (pitch) when it is traveling at a constant velocity or a = 0 . Draw a graph on a chalk (white?) board.

Now elevate that same end several inches (cms.) and let the sphere roll down the track freely (3.). You will clearly see and hear the sphere accelerate; it appears to have a constant (uniform) acceleration. Draw another graph on the board; the line should be a straight incline representing constant acceleration. Elevate the track further and repeat the roll; add another steeper straight line on the graph.

If you add a third trial that illustrates an even greater acceleration, you have reached a point where you can now clearly demonstrate a non-uniform acceleration. From being level, just keep elevating the end of the track while the sphere rolls down it (4.). You can see, but especially hear, the changing velocity and acceleration. Draw another graph but with a curve illustrating non-uniformity.

(b) A nearly frictionless pulley, two 50 gm, hooked masses, and paper clips. Set the pulley high up off the classroom floor and measure out a strong nylon thread that reaches from the pulley to the floor; add a little extra length for the pulley and knots. Attach a paper clip to each end of the thread, and bend each clip to make a "hook". Put the thread over the pulley. One mass should be resting on the floor, the other near the pulley, ready for a trial (5.).

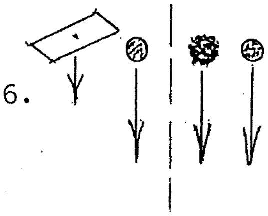
5.



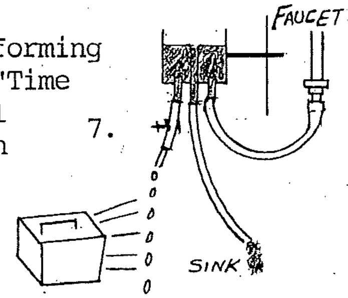
Presentation: With your finger, give the top mass a light, but firm, push downward. You should witness a smooth, constant velocity downward. Repeat. With the top mass near the pulley, carefully add two paper clips to the "hook" which will unbalance the system and provide an unbalanced force to cause acceleration. The top mass with the added clips will demonstrate a smooth, constant acceleration downward. Add two more clips and repeat for a greater acceleration. If you performed the "track" demo first, reuse its graphs for the "pulley" demo. To duplicate the non-uniform acceleration with the pulley, keep adding paper clips to the top mass on its way down. This is difficult to do, but the students should get the idea anyway.

Free-fall is the study of the motion of an object in the earth's gravitational field <u>regardless</u> of its mass. The first person who studied gravity and its effects leading to "g", the acceleration due to gravity, was Galileo in the 1580's. If you go back to the "track" demo (inclined plane) and repeat it, you are doing what Galileo did. However, being the mathematician that he was, he continued to raise the track until it was straight up. Using the graph and extrapolation, he was able to arrive at a good approximation of the value of "g" and concluded that it was a constant for all free-falling objects. This great discovery overturned Aristotle's teaching from the 360's B.C. that heavier objects fall faster than lighter objects.

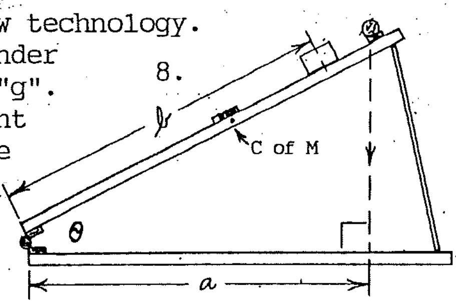
(c) A very simple demonstration to prove Galileo's conclusion (6.). Take a half sheet of $8\frac{1}{2}$" x 11" paper and a golf ball and drop them to the floor. Result: the heavier golf ball wins. Now crumple the paper sheet into a tight ball and repeat the drop. Result: it's a tie even though the golf ball is about 18 x heavier. Of course, air resistance is always a factor in any kinematics and free-fall study; however, to keep things simple in high school physics, we neglect it most of the time. Galileo had to do the same in the 1580's.

6. 

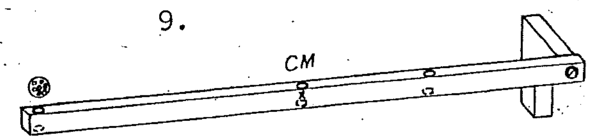
(d) To actually see a beautiful "g" pattern, consider assembling and performing the free-fall of water droplets using a stroboscope (7.). The topic "Time and timing" elsewhere on this website fully describes this delightful demonstration. It requires some extra effort, but the result is worth it.

7. 

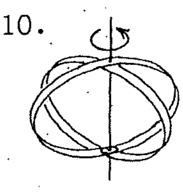
(e) One of the oldest demonstrations concerning "g" is "Free-fall bodies - the hinged board with cup" which is to be found fully described elsewhere on this website. It concerns the importance of the center of mass when discussing "g" and the free-fall of an object (8.). The result is meant to surprise the students. The action is faster than the eye but may be "caught" with the new technology.

8. 

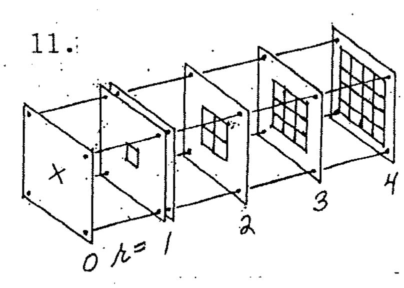
(f) Generally, "g" is a constant for all free-fall objects, but under certain circumstances, an "object" can free-fall faster than "g". The demonstration in (e) proves that it can. However, the event is much too fast for the eye to understand. Fortunately, there is a way, without high-tech, to observe different values of "g" associated with the "falling" hinged board. Look up the topic "The "g" stick" on this website for a full description (9.). It's something the students can participate in (perform) via low or high technology. The stick is easy to make.

9. 

(g) It has long been known that the value of "g" is not truly a constant but varies everywhere because of the varying distance from the center of gravity (mass) of the earth, e.g.,elevations and latitudes. The "latitude" variable is due to the earth's deformation caused by its high speed rotation on its axis. All points on the equator are traveling over 1,000 mph which results in a "bulge" around the equator or the points are further from the center while simultaneously the poles are "flattened" or closer to the center, thus two different values of "g". It has been said that a 167 lb. person at the North Pole would only weigh 166 lbs. at the equator. The simple demonstration that illustrates this phenomenon best is found in the topic, "The rotator", part (c) with the flexible hoops on a spinning shaft (10.). The apparatus is still commercially available.

10. 

(h) Another possible way of explaining how the value of "g" changes around the earth is by considering how the earth's gravitational field strength (spacing of the lines of force) changes with distance from its center. This study is made easier with a 3-D model (11.). This model is fully explained in the topic, "The inverse square relationship". It emphasizes the earth's expanding (radial) lines of force out into space. It is not difficult to make and will help explain several other important topics, also.

11. 

(i) Around 1970, the national physics program, "Harvard Project Physics", addressed the topic of kinematics using a new piece of apparatus, the liquid accelerometer (12.). It went a long way toward "illustrating" and explaining constant velocity and acceleration. A full explanation of the accelerometer and its many uses can be found on this website at "Acceleration and the HPP liquid accelerometer". Its use is recommended.

12.