Topic 8: Gravitation

Source:	*Conceptual Physics* textbook, lab book and CPO textbook and lab book
Types of Materials:	Textbooks, lab books, worksheets, demonstrations/activities, vectors and websites, and good stories
Building on:	After studying dynamics and learning how force affects motion, the concept of gravitational force fields is introduced, such as the force field around the earth. The world was nicely introduced to force fields in the first Star Wars movie in the late 1970's. Acceleration of gravity (9.8 m/s/s) could have been done during dynamics or at this time, which is where I am placing it to show the "downward vector nature" of this topic. Following the sequence of topics presented thus far, using centripetal force, some algebra and a new topic of the Universal Law of Gravitation, students can understand satellite motion as well as calculate, if one desires, satellite speed, orbit radius, and the acceleration of gravity at all points in space. Furthermore, using energy principles, the student can understand, and even calculate, escape velocity from earth, and bound and unbound satellite orbits.
Links to Physics:	As mentioned in the "building on" above section, satellite motion is a natural follow-up to studying gravitation. Gravitation plays a direct role in friction as previously presented in kinematics. Recall that friction is directly proportional to the normal force pressing two surfaces together, which is often gravity. When gravity is considered for forces between atomic particles, we see it plays a very small role since it is so small compared to the other force laws of nature. So, on the nuclear and atomic level, gravity is there but it isn't much of a factor. Gravitation plays an important role in planetary motion, space travel, movement within solar systems of moons and asteroids and the holding of solar systems together, and the formation of comets, planets and asteroids. Let's not forget the formation of stars and galaxies within the universe.
Links to Chemistry:	Spectrum analysis of stars can give us the information needed to determine their chemical make-up. Meteorites that land on earth can be chemically analyzed to determine their make-up and piece together ideas on the formation of the universe. Our moon samples taken from the moon give scientists ideas about the formation of our solar system. Due to the small effect of gravity on atomic and nuclear forces, gravity in chemistry is no real factor.
Links to Biology:	NASA astronauts have done science (including biology) experiments in non-gravity conditions and compared them to on earth situations. On earth, crystals can be grown, but 0-g conditions produce better results. In

1991, the STS-40 crew of the Space Shuttle Columbia began an exciting mission to understand how living things function in the microgravity environment of Earth's orbit. Experiments were done on jellyfish ephyrae and their gravity receptors. Also, experiments on human systems including cardiovascular/cardiopulmonary, homological, muscular, skeletal, vestibular, immune and renal-endocrine were performed and compared to earth (gravity) functions.

Materials:

(a) Hewitt

2. Lab 36 – Acceleration of Free Fall
3. Lab 37 – Computerized Gravity
4. Lab 38 – Apparent Weightlessness

(b) Hsu*

(c) Mine
Measure "g"

(d) Worksheet
Gravitational Field

(e) Demonstration
Up and Down "g"

(f) Videos and Websites

1. The g-Force Experiment
Funderstanding & Question 3D Coaster Lab Sim (Shockwave/Java)
2. http://www.space.com/businesstechnology/technology/anti_grav_000928.html
(This site discusses work underway on creating an anti-gravity device.)
3. http://www.sciencedaily.com/release/2006/03/06032222521.htm
(This site discusses an 18-month gravitational-wave search by a NASA-funded project.)
4. http://www.space.com/scienceastronomy/equator_bulge_020801.html)
(This site explores the Earth's gravitational shift resulting from the bulging of the equator.)

(g) Good Stories

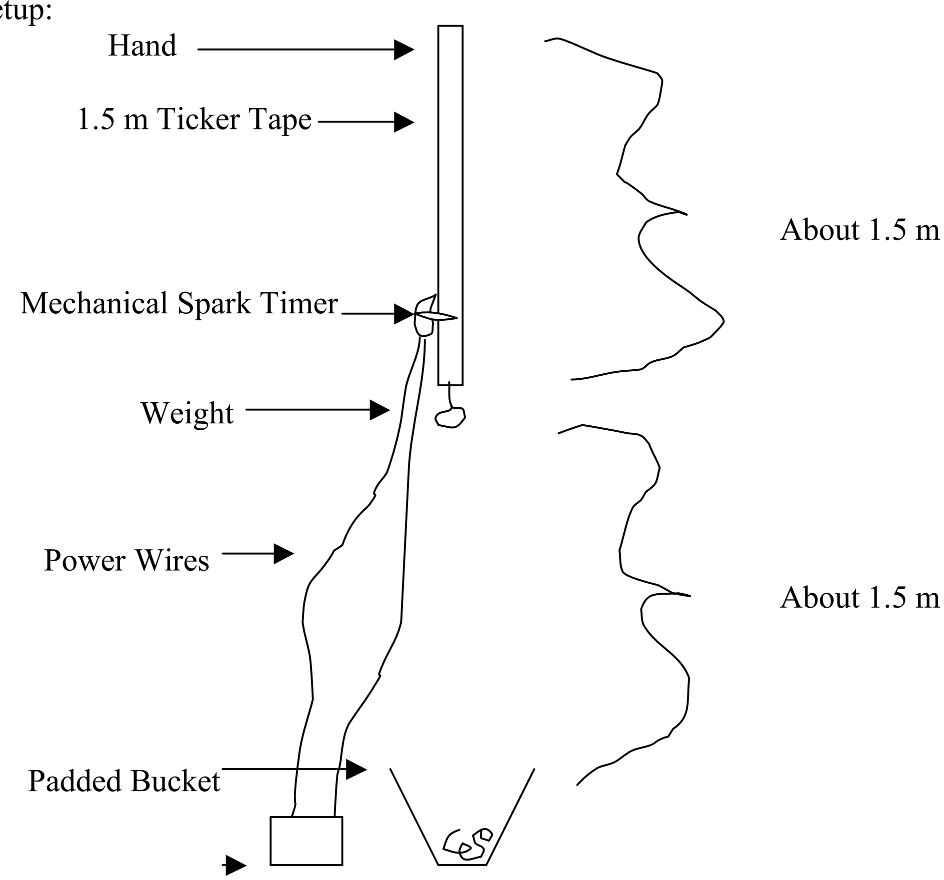
1. Johannes Kepler – The Father of Sci-Fi
2. Johannes Kepler – Amazing Accomplishments
3. Tycho's Knows
4. Tycho's Pet Moose

Topic 8: Lab – Measuring "g"

Purpose: To measure the acceleration due to gravity at the earth's surface conceptually or numerically.

Theory: Many authors have written fine labs on finding "g." Some approaches include: dropping an object from a tall location and measuring the distance of drop and the time of drop and then using a formula to find "g"; drop an object past sensors that start and stop time on a clock—this can be read by a computer to result in great times; use photography or a spark timer to obtain the position of an object at several times. The electronic spark timer sold by most science supply company's works great and I have used it often. No friction (except air) gives the great result, however, if cost, storage, and being very heavy are an issue to you, then here is an alternative. This setup is easy to assemble, inexpensive, easy to store, yet use the same "physics thinking" as the standard spark timer.

Setup:



Procedure:

1. Set up a reliable mechanical spark timer (hopefully the timer I referred to in Topic 3 will soon be available) about 1.5 m above the floor.
   (a) Attach the long electrical connection to a power supply.
   (b) Test and make adjustments to the timer to obtain dark consistent dots on the paper tape.

2. If you want a value for "g," the timer must be calibrated:
   (a) Pull a ticker tape through the vibrating timer for say 3 s and count the dots. Calibrate: Example – In 3 s (stop watch) you get 301 dots or 300 intervals. Thus, 3 s/300 spaces = 0.01 s/space.
   (b) A more convenient and accurate method is to use a strobe light. If you have calibrated one, the time = 1/strobe frequency.

   If you want to show "g" is constant, but without determining its value, you can make up a time like in the days of PSSC physics. Call the interval a "tick" (or tock if you prefer). Pretend that 10 spaces equal 0.1 s. The final graphs for (a) or (b) the "tick" time approach will all be an angled straight line when you construct an average velocity vs. time graph. This will show that "g" is constant at 9.8 m/s/s or just constant.

3. Tape a weight (about 500 g) to the timer tape and thread through the timer.

4. With the timer operating, drop from rest the weight and attached tape with your grip at the top of the tape into the padded bucket.

5. On the tape, mark off equal time intervals (equal number of spaces) that is mathematically convenient or just convenient if you are just showing a constant "g." You should have five or more intervals to see the trend on the graph. Be sure not to include any data points at the very beginning to ensure free fall is occurring or at the very end in case the weight is in the bucket.

6. Record the length of the first interval in the table. Repeat for the other intervals. Record the same interval time next to each interval distance in the table. Divide the interval distance by the interval time and record as the average interval velocity. Make a new total time column in the table.

Interval Distance (m)	Interval Time (s or tick)	Average Interval Velocity (m/s or m/tick)	Total Time (s or tick)

7. Plot an average interval velocity vs. total time graph. Even though the data plot will not be plotted at the correct real total time, it doesn't matter since the average velocity vs. total time graph is equal to $\vec{g} = \Delta\vec{v} / \Delta t$, so the CHANGE in time is what counts which will be correct.

8. Take the slope of this graph: ($\Delta v / \Delta t$), which will be the average acceleration caused by gravity.

Questions:

1. What is the direction of acceleration caused by gravity?

2. Is g a scalar or vector?

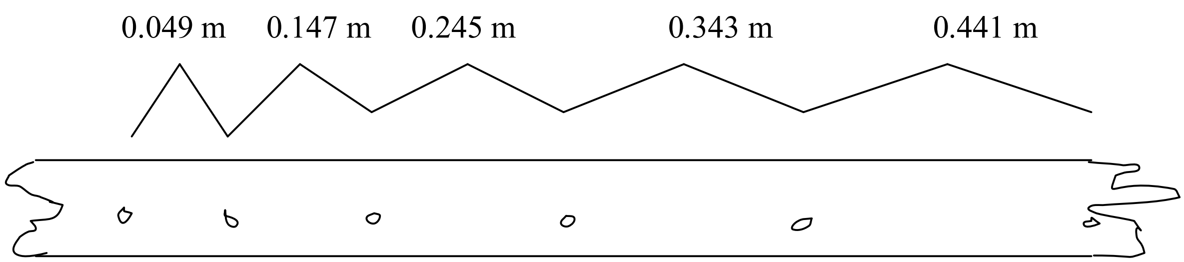
3. Is g a constant or does it vary?

4. What is the value of g at the earth's surface?

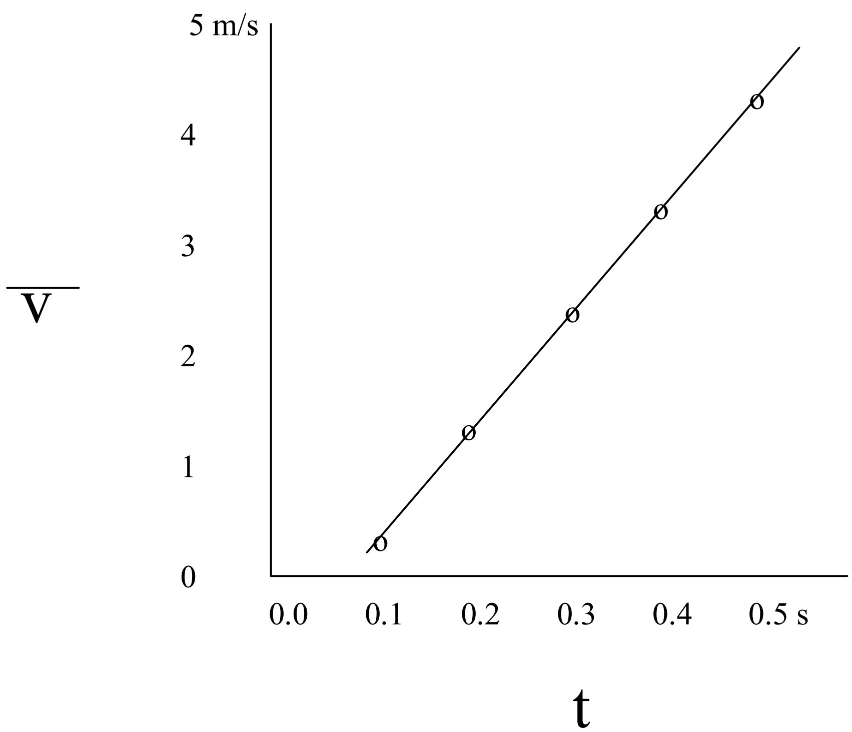
5. What ways do you have to improve on the outcome of the data?

Topic 8: “g” Lab Answer Sheet – Sample Data Below

Interval Distance (m)	Interval Time (s or tick)	Average Interval Velocity (m/s or m/tick)	Total Time (s or tick)
0.049 m	0.1 s	0.49 m/s	0.1 s
0.147	0.1	1.47	0.2
0.245	0.1	2.45	0.3
0.343	0.1	3.43	0.4
0.441	0.1	4.41	0.5



Average Interval Velocity vs. Total Time



$$\overline{g} = \Delta\overline{v} / \Delta t$$

$\overline{g}$ = (4.41 - 0.49 m/s) / (0.5 - 0.1 s) = 9.8 m/s^2 Slope from graph

Questions:
1. Direction of acceleration caused by gravity is DOWN; “g” is $\downarrow$.

2. Vector (down)

3. Constant (Slope of graph is the same—constant.)

4. 9.8 m/s^2 if real distance and time are used.

5. Improve measurements of time and distance. (Use electronic spark timer instead of mechanical timer.)

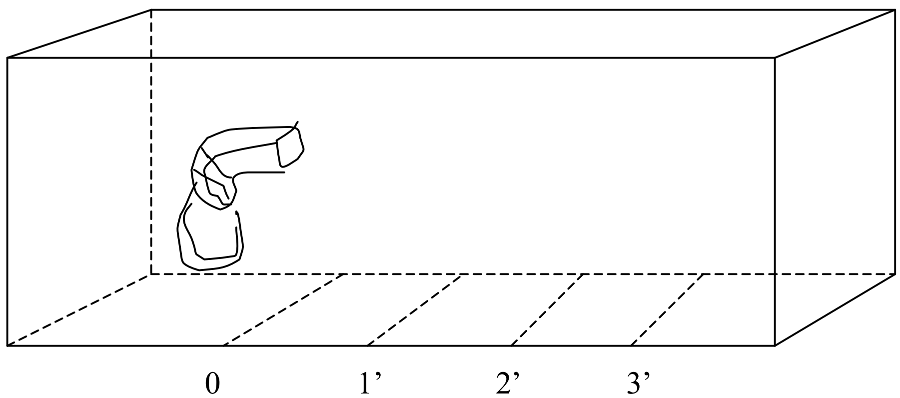
Topic 8: Worksheet on Gravitation

(A) Gravitational Fields

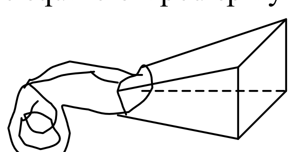
In nature, one mathematical relationship exists in several situations. That relationship is called the inverse square law, and it works for gravity and other situations where something spreads out from a point in a radial direction or out from a center point. The spokes of a bicycle wheel illustrate this idea in two dimensions. Gravitational fields behave like spokes but are in three dimensions.

A visual example of this law appears below for a fictitious example used in a high school physics program called PSSC (Physical Science Study Committee) physics.

Visual: Imagine a liquid butter gun capable of shooting a uniform mist from a square nozzle located in an antigravity chamber (sound silly?). The butter would travel through the chamber in straight lines (no gravity).



Now imagine placing one slice of bread at 1 foot in front of the nozzle. With a squeeze of the butter gun you find the square-shaped spray covers perfectly.

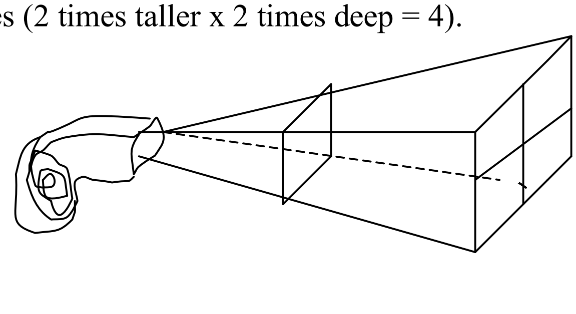


What would happen to the spray pattern if you moved to 2 feet from the nozzle? How many pieces of bread would be uniformly covered at 2 feet?

(a) ________________________________ (b) ________________________________

If you wrote two slices, you would be incorrect since the butter spreads out up and down but also in and out of the sketch.

The answer is four slices (2 times taller x 2 times deep = 4).



At 2 feet, what amount of butter covers each slice compared to 1 foot?

____

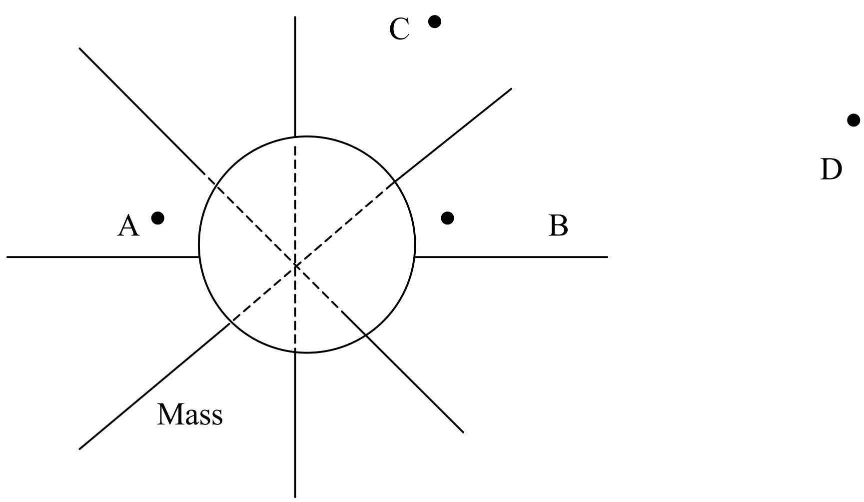
What correct math relationship exists between distance and the amount of butter per slice (consider as distance increases, the amount of butter per slice decreases)? Be careful.

____

At 3 feet, what amount of butter per slice covers one slice of bread compared to 1 foot?

____

Now, let's show the connection between the above example and GRAVITY. This sketch shows the GRAVITATIONAL FORCE FIELD around a mass in two dimensions.



Sketch X

Points A and B are the same distance from the center of the mass. Point C is twice the distance to the center of mass and point D is four times the distance as A and B.

Questions?

1. How does the force of gravity on a mass compare at points A and B?

____

2. How does the force of gravity on a mass at C compare to point A?

____

3. How does the force of gravity on a mass at D compare to A?

____

From dynamics, F = m a. The force of gravity on a mass created by a second mass is $F = F_s$ = weight (call it w).

4. If a mass is dropped from point A, which way does it fall?

____

5. If a mass is dropped from point B, which way does it fall?

____

6. What would you call the acceleration on the mass at point A?

____

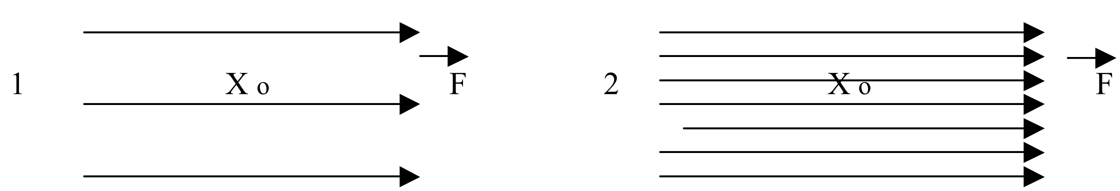
7. Using symbols, what is the math relationship between the weight and mass and acceleration of a body?

____

8. Sketch weight vectors to scale on sketch X.

(B) Acceleration of Gravity at Different Locations
When gravitational force field lines (vectors) are close together, that indicates the strength (force/mass) is larger (g = F/m).

This example shows force field 1 and force field 2 with point X between the lines.



Which field is stronger? By looking at both sketches, 1 and 2, we see field 2 is stronger because the gravitation force field lines are closer together.

Also, the gravitational force field obeys the inverse square law as decreased in (A), so $F \propto 1/R^2$. So, if R is doubled, F is $½^2$ or ¼ as great; if R is tripled, F is $1/3^2$ or 1/9 as great.

Look at sketch X in (A) and compare the:

(a) Force field of (B) to (A):

____

(b) Force field of C compared to A:

____

(c) Force field of D compared to A:

____

Would the force field ever go to zero if a body goes far enough from the central mass?

____

What do you think happens to the force field inside the body?

____

____

(C) The Universal Law of Gravitation

Sir Isaac Newton is said to have watched an apple fall from a tree and arrive at the idea that the same force should be present on the earth from the apple as that of the earth on the apple. In other words, any two bodies in the universe attract each other with the same force, but in the opposite direction (body 1 attract body 2 and body 2 equally attracts body 1, but in the opposite direction). This is the universal law of gravitation without the math. Some everyday examples: dog attracts flea, flea attracts dog: chair attracts desk, desk attracts chair.

Furthermore, Newton arrived at a formula (not derived here) that states:

$$F_g = G\frac{(m_1 m_2)}{R^2}$$

which includes the inverse square law. F_g is the force of gravity, m_1 and m_2 are the two masses and R is the separation between their centers. G is the proportionality constant and m is mass in (kg), R is separation in (m), F is force in (N), so G results in a value of 6.67 x 10^{-11} N m^2/kg as accurately determined by Load Cavendish.

Test Your Math Skills:

(a) If one of the two masses were to magically double, the force of gravity between the two bodies at the same separation would

____.

(b) If both masses magically double, the force of gravity between the two bodies at the same separation would

____.

(c) If the separation between the same masses would halve, the force of gravity between the two bodies would

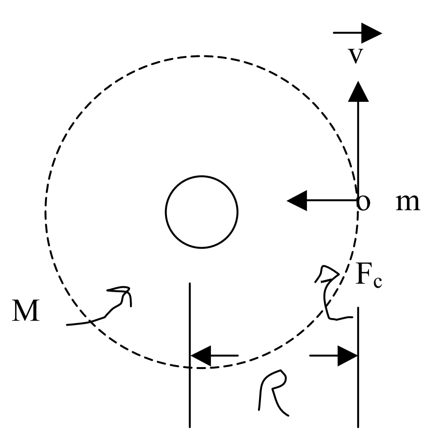
____.

(d) If both masses triple and the separation triples, the force of gravity between the two bodies would

____.

(D) Satellite Circular Motion

If a satellite is to orbit in a circular path around a central mass, only correct physical quantities will work and be mathematically appropriate. A circular orbit of the earth around the sun or the moon around the earth come close. A man-made satellite in a circular path around the earth is possible such as a communication satellite. A sketch is shown for mass (m) orbiting a large body (M) at a separation (R) and going at the proper velocity (v) to maintain circular orbit.



The force between the two bodies is gravity, which is also a centripetal force; therefore, we can write:

Force of gravity = Force centripetal

$$F_g = F_c$$

$$\frac{GMm}{R^2} = \frac{mv^2}{R}$$

Recall that F = ma and therefore at any point in space above M, $F_s = w = mg$, thus,

$$\frac{GMm}{R} = \frac{mv^2}{R} = mg$$

From these formulas and a lot of algebra, one can calculate quantities like "g" at any point in space, "M," the mass of the central body, "v," the orbit velocity to maintain circular orbit, and "R," the orbit separation to maintain circular orbit.

Test Your Math Skills:

(a) If you were in an orbiting space ship and wanted to double your velocity, where in space would you need to go to continue your circular path?

____

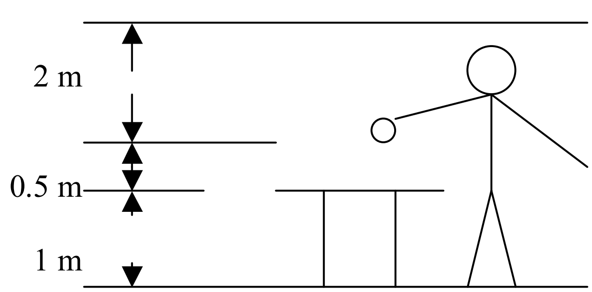
(b) If R doubles, what happens to "g" at this new location?

____

(E) Escape Velocity, Bound and Non-bound Orbits

Gravitational potential energy near earth depends on the mass, acceleration of gravity and the position of the mass (height above another point). If a 1 kg mass is 1 m above the earth with g = 9.8 m/s/s, the GPE is "mg Δ h" equaling (1 kg)(9.8 m/s/s)(1 m) = 9.8 J. However, GPE is relative, as in this sketch:

Sketch



John holds a 1kg mass 0.5 m above a 1-m-tall table in a room that is 3.5 m tall. If one asks the question, “What is the ball’s GPE?,” it is not a good question, since it doesn’t give the relative reference point. The following questions are good questions:

(a) What is the mass’s GPE relative to the table? ________________________
(b) What is the mass’s GPE relative to the floor? ________________________
(c) What is the mass’s GPE relative to the ceiling? ________________________

Work was done on the mass to get it above the table and floor, but more work would need to be done on the mass-earth system (against the gravitational field) to raise it to the ceiling; thus, the mass is MISSING ENERGY, or -GPE.

GPE is relative. GPE for planetary or satellite motion begins with a definition of 0 energy at infinity. Since the force of gravity does “work” on falling bodies, the gravitational force field “looses” energy as two bodies come closer together; the energy becomes NEGATIVE since the field does the pulling (internal work).

If a ball is thrown above the ground near the earth, the ball-earth system has both kinetic and gravitational energy to total the following:

$$E_T = KE + GPE$$

If a satellite is above the earth in an earth-satellite system, the total energy is:

Total Energy = Kinetic Energy + Gravitational Potential Energy

$$E_T = KE + GPE$$

For the satellite-earth system, a NEGATIVE GPE exists and equals $-GmM/R$ (no proof offered—calculus is required).

So, $E_T = \frac{1}{2} mv^2 - GMm/R$.

Three possibilities exist for the total energy of the satellite-central body (earth) system:

1. If KE › GPE, the satellite has so much motion (kinetic) energy that the satellite will escape with plenty of KE, which illustrates a non-bound system.

2. If KE is ‹ GPE, the satellite cannot escape, like a baseball tossed near the earth, and will return to the earth showing a bound system.

3. If KE = GPE, the satellite is not bound and can escape the earth, which is called the escape velocity (what goes up DOESN’T have to come down).

Questions:

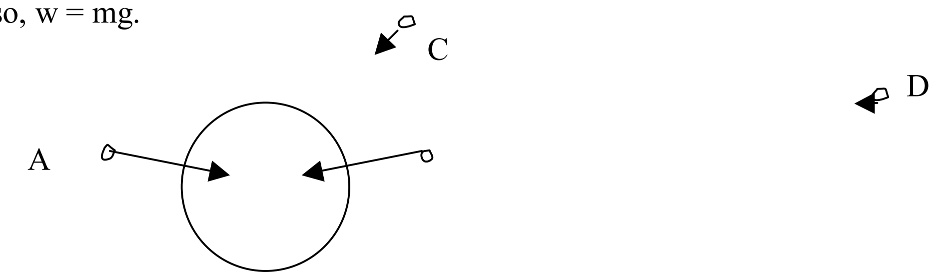
(a) How could you calculate “escape velocity” from earth?

(b) What quantities would you need to know to escape from earth?

Topic 8: Gravitational Worksheet Answer Sheet

A. 1. (a) The spray expands. (b) 4
2. 1/4 as much
3. As distance increases, the butter per slice decreases; specifically, the inverse square law is illustrated.
4. 1/9 as much

1. Same
2. $F \propto 1/2^2 = 1/4$ as much
3. $F \propto 1/4^2 = 1/16$
4. Toward the center of the large mass
5. Toward the center of the large mass
6. Acceleration of gravity (g)
7. F = ma, so, w = mg.
8.



B. Field 2 is stronger.
(a) Same
(b) 1/9 as much
(c) 1/16 as much

No, at greater distances, the force field approaches 0, but never reaches zero.

The force field inside a mass actually decreases linear from the top surface inward to the center (requires calculus proof).

C. (a) Double (m is 2x; F is 2x.)
(b) Quadruples (4x) (m_1 is 2x, m_2 is 2x, so F is 2 x 2 = 4.)
(c) 1/4 (1/2 x 1/2 = 1/4)
(d) (3 m)(3 m) / (3) = 1, or the same.

D. (a) $Gm/R^2 = mv^2/R$ $v = \sqrt{GM/R}$

For v to double (2 v) while G & M are constant, R must be 1/4 the original R.

(b) $gm = GMm/R^2$, so, $g = GM/R^2$. If R doubles, g is 1/4 ($1/2^2$).

E. (a) mgh = (1 kg)(9.8 m/s/s)(0.5 m) = 4.9 J
(b) mgh = (1 kg)(9.8 m/s/s)(1.5 m) = 14.7 J
(c) mgh = (1 kg)(9.8 m/s/s)(-2 m) = -19.6 J

(a) $E_T = 1/2\ mv^2 - GMm/R$
Set $E_T = 0$, so $1/2\ mv^2 = GMm/R\ v^2 = 2\ GM/R$.

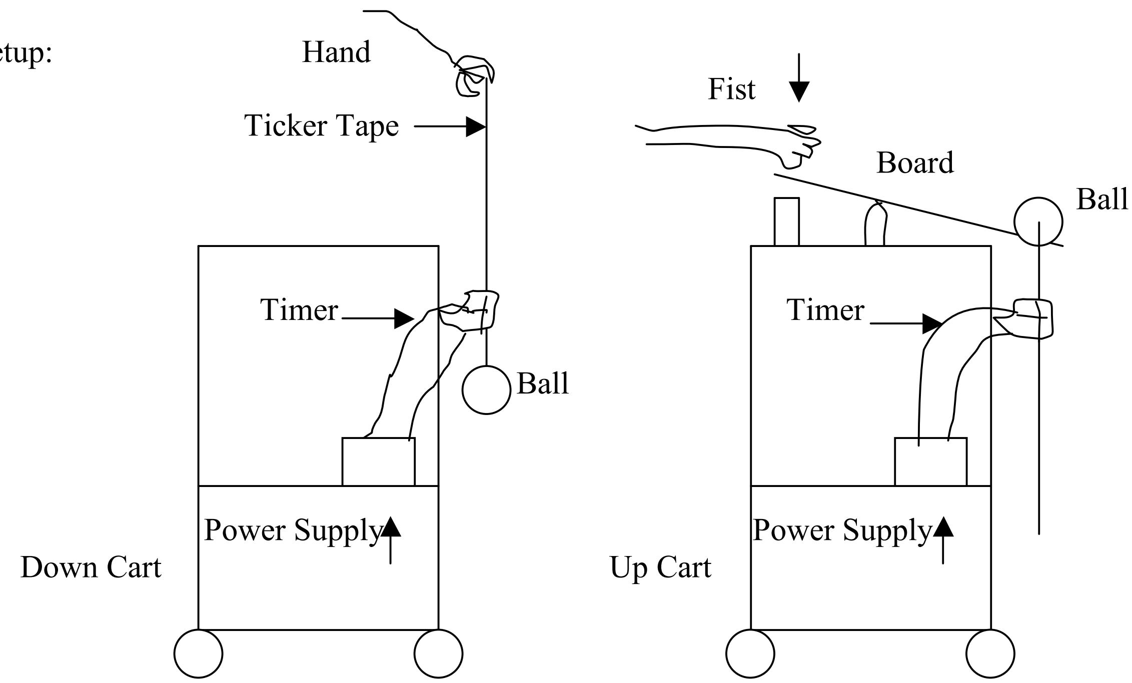
$v = \sqrt{2\ GM/R}$ escape velocity

(b) 1. Universal constant
2. Mass of earth
3. Radius of earth

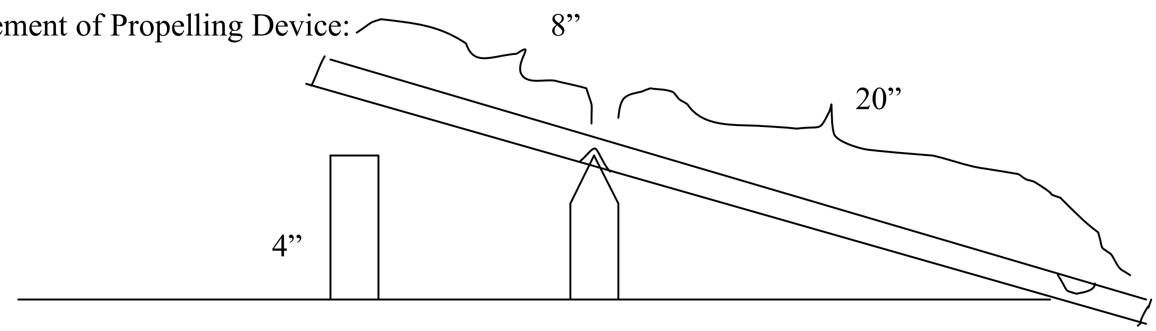
Topic 8: Demonstration: Up and Down – g

Purpose: To compare “g” going up and “g” going down. Are they the same or different?

Setup:



Enlargement of Propelling Device:



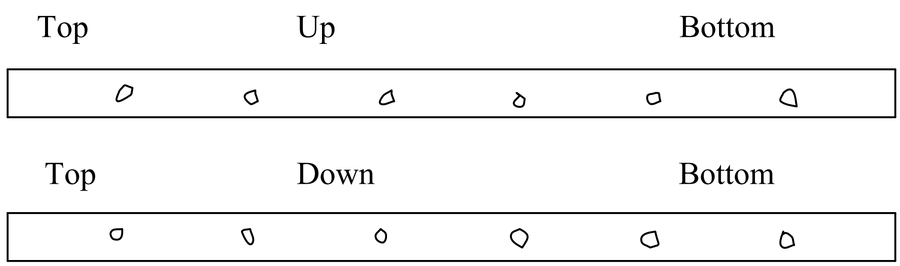
Procedure:

“g” going down

1. Set up the power supply and mechanical ticker timer on the side of a tall cart near the top of the cart (see sketch).
2. Test the timer to give consistent and dark carbon dots on a practice ticker tape.
3. Tape a 1 m ticker tape to the baseball. Label the tape “down” and write on the top of the tape “top” and “bottom” for the end of the tape attached to the ball.
4. Thread the tape upward through the timer so the ball is near the timer (sketch).
5. Hold the tape at the top and hold the tape and ball at rest. Start the timer.
6. Drop. Put the tape on a flat table.

“g” going up

1. Make a 1” x 4” x 28” board with a pivot notch about 8” from one end. Create an indentation for the ball to rest on about 1” from the other end.
2. Set up as shown with the notch in the board resting atop a knife edge made on the top of a 2” x 4” piece of wood.
3. Place a 2” x 4” x 4” wood stop under the 8” end of the board.
4. Tape a 1 m ticker tape to the baseball. Label the tape “up” and also write on the tape “top” near the ball and “bottom” near the end by the floor.
5. Thread the tape down through the timer (sketch) and pull snug.
6. With the timer on, firmly strike the 8” end of wood downward to the stop. The ball will fly up and out of the timer.
7. Align this “up” tape next to the “down” tape with top next to top and bottom next to bottom.



8. Compare about 40 cm from the center sections of the two tapes insuring both tapes are in free fall.
9. Slide one of the tapes back and forth to see if dots match up. If dots match side by side, what does this show about “g” going up and down?

   <u>Answer</u>:
   The dots can be adjusted so they are side by side, showing the value of “g” is the same going up as down. With up being defined as +, g becomes negative because the ball slows down (Δ v is -). With down being defined as “negative,” g is – because Δ v is + but the direction is -.

Johannes Kepler – The Father of Sci-Fi

In his early days at university, Kepler wrote one of his required dissertations in response to a challenge made by Michael Maestlin, a believer of Copernicus and one of the most learned astronomers of all time. The subject of the thesis is how phenomena occurring in the heavens would appear if observed from the moon. The thesis was never published but the idea led Kepler to write the story, “Somnium” (The Dream), about a man who travels to the moon and describes his experiences.

Our traveler describes the forces necessary to propel a body against earth’s gravity. Kepler suggests numbing the body and arranging the limbs so that they will not be torn apart by the “force of acceleration.” He also warns of the dangers in breathing the extremely cold air in space. It seems that Kepler could not imagine a vacuum in space. Once free of earth, “the bodily mass proceeds toward its destination of its own accord. Here Kepler introduces the concept of inertia. During the journey the traveler must be shielded from deadly solar radiation by traveling during the lunar eclipse, the earth’s shadow providing the necessary protection.

Kepler recognized that in a dynamic Copernican system, the path traveled from earth to the moon is not a straight line, but rather a trajectory from earth to a point in space where the moon and the lunar voyager would arrive simultaneously. Today this path is called a transfer orbit.

Kepler spent most of his life perfecting “The Dream.” Future writers of cosmic voyages would find Kepler’s work inspiring. Jules Verne, H. G. Wells and Arthur C. Clark, some of the greatest science fiction writers of all time, read the Somnium.

Johannes Kepler – Amazing Accomplishments

Johannes Kepler was a man of significant accomplishments. Presented are some of his notable discoveries.

- First to explain how an image forms in a pinhole camera.
- First to explain the process of image formation in the eye using the concept of refraction, the bending of light as it passes through a substance.
- First to design eyeglasses for correcting nearsightedness and farsightedness.
- First to explain the use of both eyes to perceive depth.
- First to describe images as real, virtual, upright and inverted.
- First to explain how the magnification results from light passing through a lens.
- First to explain how a telescope works.
- First to design and build an astronomical telescope (two convex lenses).
- First to discover and describe the properties of total internal reflection.
- First to explain how tides are caused by the moon.
- First to use stellar parallax to determine the distance to the fixed stars.
- First to suggest that the sun rotates about its axis.
- First to derive logarithms purely based on mathematics.
- First to use the term “satellite” to describe orbital motion.
- First to discover that light entering a parabolic reflector converges at the focal point of the parabola.
- First to write a true science fiction story.
- First to discover that the path of Mars is an ellipse.
- First to put forth scientific evidence to dispel Aristotle’s astronomy.

Tycho's Knows

On the tenth of December 1566, a dance was held at Lucas Bacmeister's house in preparation for a wedding. Lucas Bacmeister was a professor of theology at the University of Rostock where Tycho studied. Among the guests were nineteen-year-old Tycho Brahe and another Danish nobleman, Mauderup Parsberg. An argument erupted and they separated in anger. Several weeks later on December 27, the argument started again.

It seems that Brahe and Parsberg had competed in studying mathematics and other higher sciences. Apparently the quarrel centered on who was the more skilled mathematician and, in the evening of December 29, tempers flared and a duel was held. The two men, armed with rapiers, faced each other at 7 P.M. in total darkness. The duel ended with Parsberg cutting Tycho on the bridge of his nose. In this encounter Tycho lost the front part of his nose. Tycho had an artificial nose made, not from wax but from an alloy of gold and silver and put it on so skillfully that it looked like a real nose. A close friend of Brahe is reported to have said that Tycho used to carry a small box with a paste, with which he would often "put on the nose."

Tycho's grave was opened on June 24, 1901 on the three-hundredth anniversary of his death. On the front of his cranium there were clear green marks. Evidently the metal piece of his artificial nose must have had a significant amount of copper also. The hostility between Tycho and Parsberg however was not lasting, and Parsberg became one of Tycho's greatest supporters under the Danish king, Christian IV.

Tycho's Pet Moose

A famous story about Tycho Brahe is about his tame pet moose. Tycho had extensive mail correspondence with Lantgrave Wilhelm of Kassel in Germany about astronomical events. In 1591 Lantgrave wrote to Brahe about an animal he had heard about called "Rix," which was faster than a deer but had smaller horns. Tycho replied that such an animal did not exist, but maybe he meant the Norwegian animal called reindeer. He also wrote that he would check about such animals and if he could perhaps send one. Tycho added that he had a young moose so tame that the moose would follow him like a dog and that he would send it if Lantgrave so desired.

Lantgrave replied that he had reindeers before but that they died in the heat. But he would gladly accept a tame moose and would reward Tycho with a fine riding horse for his efforts. In the meantime, Tycho had loaned out his pet moose to entertain a group of noblemen in the castle of Landskrona in a nearby city.

It seems that during the dinner the moose had wandered upstairs and had gotten into the castle's store of beer. The moose had drunk so muck beer that he became drunk, fell down the stairs and broke a leg. Despite the best care, the moose died shortly thereafter. Tycho then wrote to Lantgrave explaining the problem and said that he would be glad to order another moose.

Nicolas Copernicus

Nicolas Copernicus was born in northern Poland in 1473. At the age of ten his father had died and the church became his home. Nicolas was appointed canon at age 24 and held that position until he died in 1543. He studied mathematics, astronomy, medicine, church law and painting. The picture typically associated with Copernicus is a self-portrait. He lived in the time of Michelangelo, Leonardo da Vinci, Gerrard Mercator and Christopher Columbus. Copernicus was truly a renaissance man.

Copernicus became interested in the fact that, since its beginning, the Julian calendar, instituted in 45 B.C., showed a difference of ten days between the predicted and the actual spring equinox. He turned to Ptolemy's Almagest only to find it complicated and confusing. Ptolemy had taken Aristotle's stationary, earth-centered heavens and added a system of epicycles and deferents to explain planetary motion. As a purely academic and aesthetic exercise, Copernicus asked the question: "What if"? "What if the stationary earth was replaced by a moving earth"? How would Ptolemy's universe change?

The resulting heliocentric system did not replace the epicycle and the deferent, nor did it fit the observable facts any better. The Copernican system could not predict the position of the planets with any more accuracy than the Ptolemic system. Copernicus devised no experiment, collected no data, derived no new mathematics or offered any proof.

The appeal and acceptance of the Copernican system was its simplicity and elegance. The proofs were left to Tycho Brahe and Johannes Kepler.