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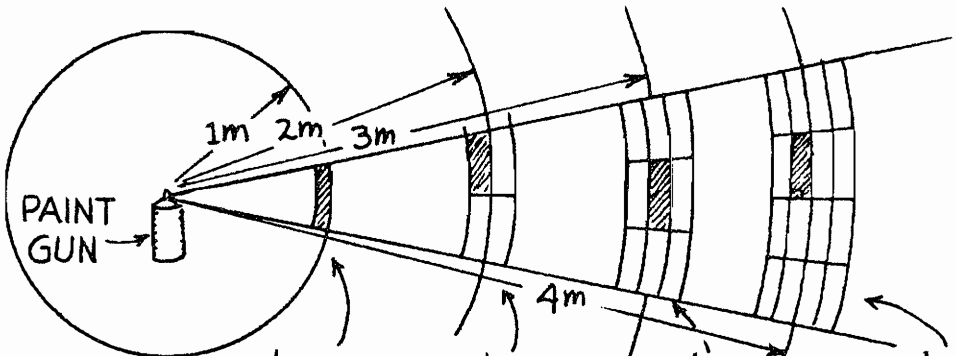
Inverse–Square Law

1. Paint spray travels radially away from the nozzle of the can in straight lines. Like gravity, the strength (intensity) of the spray obeys an inverse-square law. Complete the diagram by filling in the blank spaces.

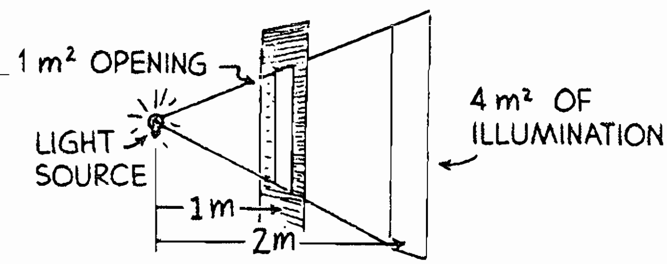


	1 AREA UNIT	4 AREA UNITS	( ) AREA UNITS	( ) AREA UNITS
PAINT SPRAY	1 mm THICK	¼ mm THICK	( ) mm THICK	( ) mm THICK

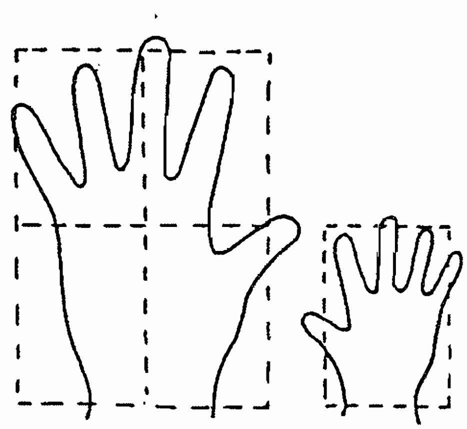
2. A small light source located 1 m in front of an opening of area 1 m^2 illuminates a wall behind. If the wall is 1 m behind the opening (2 m from the light source), the illuminated area covers 4 m^2. How many square meters will be illuminated if the wall is

5 m from the source?________________

10 m from the source? ________________



3. Hold your hands outstretched, one twice as far from your eyes as the other, and make a casual judgment as to which hand looks bigger. Most people see them to be about the same size, while many see the nearer hand as slightly bigger. Almost nobody upon casual inspection sees the nearer hand as four times as big. But because your vision depends upon an inverse-square law, the nearer hand should appear twice as tall and twice as wide, and therefore occupy four times as much of your visual field, as the farther hand. Your belief that your hands are the same size is so strong that you likely overrule this information. Now if you overlap your hands slightly and view them with one eye closed, you'll see the nearer hand as clearly bigger. This raises an interesting question: What other illusions do you have that are not so easily checked?



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6.6 Newton's Law of Gravity

21. Is the earth's gravitational force on the sun larger than, smaller than, or equal to the sun's gravitational force on the earth? Explain.

22. Star A is twice as massive as star B.

   a. Draw gravitational force vectors on both stars. The length of each vector should be proportional to the size of the force.

   b. Is the acceleration of star A larger than, smaller than, or equal to the acceleration of star B? Explain.

23. The quantity y is inversely proportional to the square of x and $y = 4$ when $x = 5$.

   a. Write an equation to represent this inverse-square relationship for all y and x.

   b. Find y if $x = 2$. ____________ c. Find x if $y = 100$. ____________

   d. By what factor must x change for the value of y to double? ____________

   e. Compare your equation in part a to the equation from your text relating the force of gravitational attraction of two objects F to the distance between them r,

   $$F_{1\text{ on }2} = F_{2\text{ on }1} = \frac{Gm_1m_2}{r^2}.$$

   Which quantity assumes the role of x? ______

   Which quantity assumes the role of y? ______

   What is the constant of proportionality relating F and r^2? ____________

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Force and Weight

1. An apple that has a mass of 0.1 kilogram has the same mass wherever it is. The amount of matter that makes up the apple

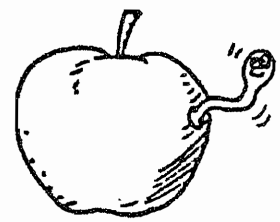
   (depends upon) (does not depend upon)

   the location of the apple. It has the same resistance to acceleration wherever it is — its inertia everywhere is

   (the same) (different).

   The weight of the apple is a different story. It may weigh exactly 1 N in San Francisco and slightly less in mile-high Denver, Colorado. On the surface of the moon the apple would weigh 1/6 N, and far out in outer space it may have almost no weight at all. The quantity that doesn't change with location is

   (mass) (weight),

   and the quantity that may change with location is its

   (mass) (weight).

   That's because

   (mass) (weight)

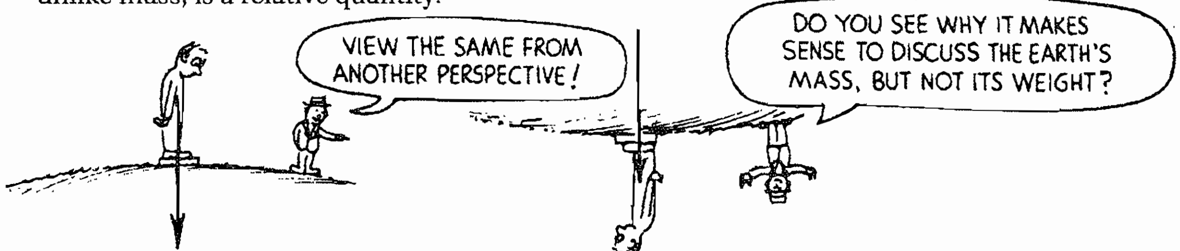
   is the force due to gravity on a body, and this force varies with distance. So weight is the force of gravity between two bodies, usually some small object in contact with the earth. When we refer to the

   (mass) (weight)

   of an object we are usually speaking of the gravitational force that attracts it to the earth.

Fill in the blanks:

2. If we stand on a weighing scale and find that we are pulled toward the earth with a force of 500 N, then we weigh ________ N. Strictly speaking, we weigh ________ N relative to the earth. How much does the earth weigh? If we tip the scale upside down and repeat the weighing process, we can say that we and the earth are still pulled together with a force of _______ N, and therefore, relative to us, the whole 6 000 000 000 000 000 000 000 000-kg earth weighs ________ N! Weight, unlike mass, is a relative quantity.



We are pulled to the earth with a force of 500 N, so we weigh 500 N.

The earth is pulled toward us with a force of 500 N, so it weighs 500 N.

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Gravitational Interactions

The equation for the law of universal gravitation is

$$F = G\frac{m_1 m_2}{d^2}$$

where F is the attractive force between masses m_1 and m_2 separated by distance d. G is the universal gravitational constant (and relates G to the masses and distance as the constant π similarly relates the circumference of a circle to its diameter). By substituting changes in any of the variables into this equation, we can predict how the others change. For example, we can see how the force changes if we know how either or both of the masses change, or how the distance between their centers changes.

Suppose, for example, that one of the masses somehow is doubled. Then substituting $2m_1$ for m_1 in the equation gives

$$F_{NEW} = G\frac{2m_1 m_2}{d^2} = 2\left(G\frac{m_1 m_2}{d^2}\right) = 2F_{OLD}$$

So we see the force doubles also. Or suppose instead that the distance of separation is doubled. Then substituting $2d$ for d in the equation gives

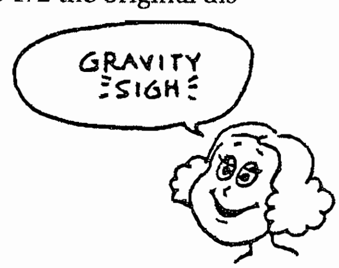
$$F_{NEW} = G\frac{m_1 m_2}{(2d)^2} = G\frac{m_1 m_2}{4d^2} = \frac{1}{4}\left(G\frac{m_1 m_2}{d^2}\right) = \frac{1}{4}F_{OLD}$$

And we see the force is only 1/4 as much.

Use this method to solve the following problems. Write the equation and make the appropriate substitutions.

1. If both masses are doubled, what happens to the force?

2. If the masses are not changed, but the distance of separation is reduced to 1/2 the original distance, what happens to the force?



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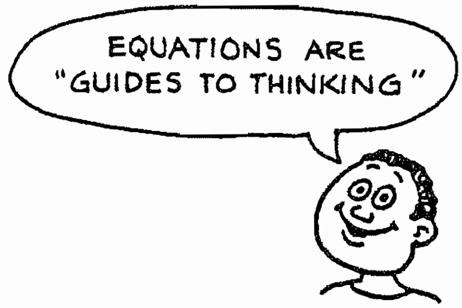
3. If the masses are not changed, but the distance of separation is reduced to 1/4 the original distance, what happens to the force?



4. If both masses are doubled, and the distance of separation is doubled, show what happens to the force.

5. If one of the masses is doubled, the other remains unchanged, and the distance of separation is tripled, show what happens to the force.

6. Consider a pair of binary stars that pull on each other with a certain force. Would the force be larger or smaller if the mass of each star were three times as great when their distance apart is three times as far? Show what the new force will be compared to the first one.

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