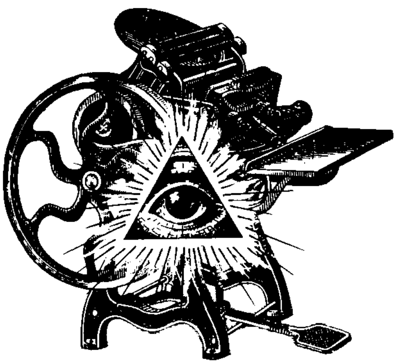
THINKING *Physics*

IS GEDANKEN PHYSICS

THIRD EDITION



DEDICATION

Most people study physics to satisfy some school requirement. A lesser number study physics to learn the tricks of Nature, so they can find out how to make things bigger or smaller or faster or stronger or more sensitive. But a tiny few, a rare tiny few, study physics because they wonder--not how things work, but why they work. They wonder what is at the bottom of things--the very bottom, if there is a bottom.

Thinking Physics is dedicated to those who wonder why. Among them was my brother, Robert Jared Epstein, Bobby.

HOW TO USE

The best way to use this book is NOT to simply read it or study it, but to read a question and STOP. Even close the book. Even put it away and THINK about the question. Only after you have formed a reasoned opinion should you read the solution. Why torture yourself thinking? Why jog? Why do push-ups?

If you are given a hammer with which to drive nails at the age of three you may think to yourself, "OK, nice." But if you are given a hard rock with which to drive nails at the age of three, and at the age of four you are given a hammer, you think to yourself, "What a marvelous invention!" You see, you can't really appreciate the solution until you first appreciate the problem.

What are the problems of physics? How to calculate things? Yes—but much more. The most important problem in physics is *perception,* how to conjure mental images, how to separate the non-essentials from the essentials and get to the heart of a problem, HOW TO ASK YOURSELF QUESTIONS. Very often these questions have little to do with calculations and have simple yes or no answers: Does a heavy object dropped at the same time and from the same height as a light object strike the earth first? Does the observed speed of a moving object depend on the observer's speed? Does a particle exist or not? Does a fringe pattern exist or not? These qualitative questions are the most vital questions in physics.

THIS BOOK

You must guard against letting the quantitative superstructure of physics obscure its qualitative foundation. It has been said by more than one wise old physicist that you really understand a problem when you can intuitively guess the answer *before* you do the calculation. How can you do that? By developing your physical intuition. How can you do THAT? The same way you develop your physical body—by exercising it.

Let this book, then, be your guide to mental push-ups. Think carefully about the questions and their answers *before* you read the answers offered by the author. **You will find many answers don't turn out as you first expect. Does this mean you have no sense for physics? Not at all. Most questions were deliberately chosen to illustrate those aspects of physics which seem contrary to casual surmise. Revising ideas, even in the privacy of your own mind, is not painless work.** But in doing so you will revisit some of the problems that haunted the minds of Archimedes, Galileo, Newton, Maxwell, and Einstein.* The physics you cover here in hours took them centuries to master. Your hours of thinking will be a rewarding experience. Enjoy!

Lewis Epstein

***Gedanken** Physics was Einstein's expression for Thinking Physics.

CONTENTS

RELATIVITY

QUANTA

Physics is what physicists do late at night.
— Joe Tenn

Mechanics

Mechanics began with the energy crisis—which began with the beginning of civilization. To make a machine that would put out more work than went into it is an ancient dream. Is it an unreasonable dream? After all, a lever puts out more force at one end than is applied to the other end. But does it put out more work? Does it put out more motion? If the lever fails, might some other scheme lead to the ultimate goal, perpetual motion? It may be said the (unsuccessful) quest to make gold launched chemistry and the (unsuccessful) quest of astrology launched astronomy. The (unsuccessful) quest for perpetual motion launched mechanics.

You may have noticed that the biggest section of this book (as well as many other physics books) is the MECHANICS section. Why is mechanics so important? Because it is the goal of physics to reduce every other subject in physics to mechanics. Why? Because we understand mechanics best. Once heat was thought to be some sort of a substance; later it was found to be just mechanics. Heat could be understood as little balls called molecules bouncing about in space or connected to each other by springs and vibrating back and forth. Sound has similarly been reduced to mechanics. Much effort has been spent trying to reduce light to mechanics.

Mechanics has two parts—the easier part, **statics,** where all forces balance out to zero so nothing much happens, and the dramatic part, **dynamics,** where all the forces do not cancel each other, leaving a net force that makes things happen. How much happens depends on how long the force acts. But "long" is ambiguous. Does it mean long distance or long duration? The simple but subtle distinction between a force acting so many feet and a force acting so many seconds is the magic key to understanding dynamics.

You'll also notice that a good deal of attention is devoted to situations involving collisions (Splat, Gush, Smush, and so on). Granted collisions are interesting in their own right, but are they all that important? Many physicists believe they are. Why? Because if all the world is to be explained mechanically in terms of little balls (molecules, electrons, photons, gravitons, etc.), then the only way one ball affects another ball is if the little balls hit. If that is so, collision becomes the essence of physical interaction.

Now it may be the goal of physics to reduce every subject to mechanics and to reduce mechanics to collisions, but certainly that goal has not been and might never be reached. Nonetheless, if you are to understand physics, you must first understand mechanics. Perhaps even love mechanics.

In learning the sciences
examples are of more use than precepts.
— Sir Isaac Newton

THINKING PHYSICS IS GEDANKEN PHYSICS

THIRD EDITION

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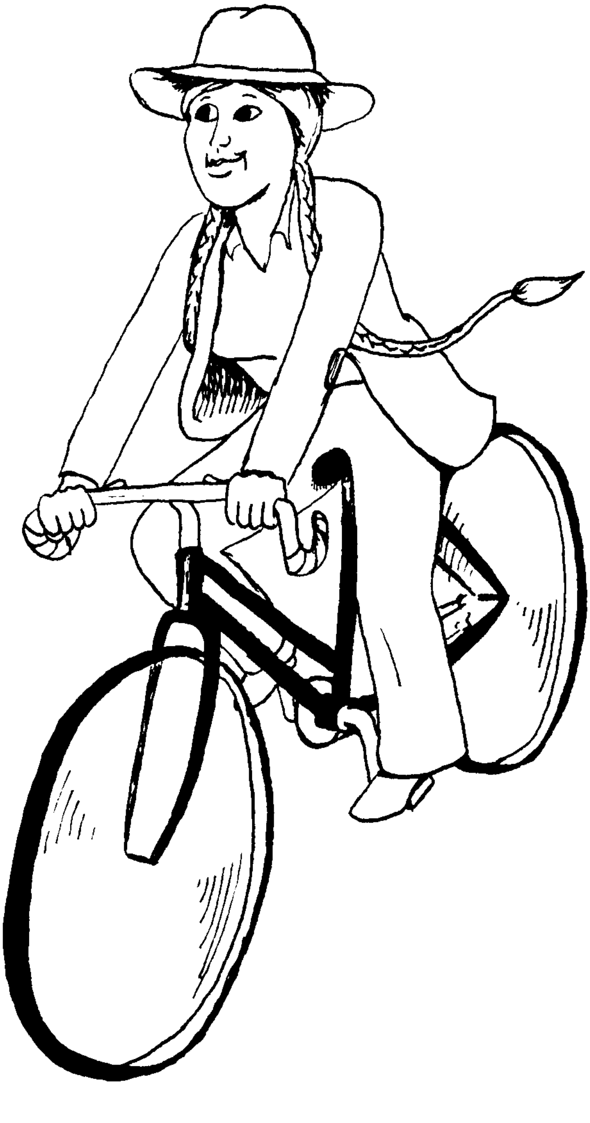
VISUALIZE IT

Suppose you are going for a long bicycle ride. You ride one hour at five miles per hour. Then three hours at four miles per hour and then two hours at seven miles per hour. How many miles did you ride?

a) five
b) twelve
c) fourteen
d) thirty-one
e) thirty-six

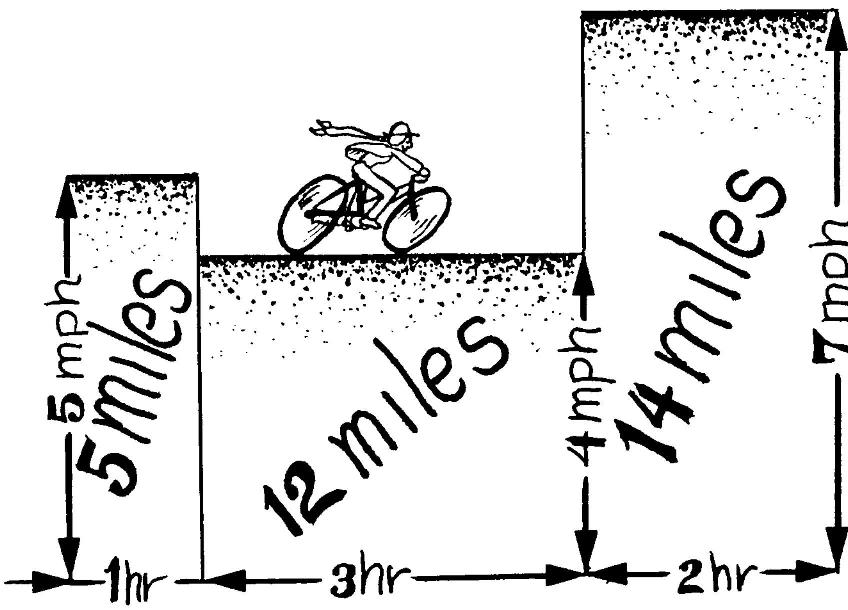


ANSWER: VISUALIZE IT

The answer is: d. Remember speed multiplied by time is distance. But what is the speed? It changes during the ride. So split the trip up into segments. One hour at five mph gives five miles. Three hours at four mph gives twelve miles and two hours at seven mph gives fourteen miles. Then add the segments. Five plus twelve plus fourteen sum to thirty-one. So that is the answer, that's it.

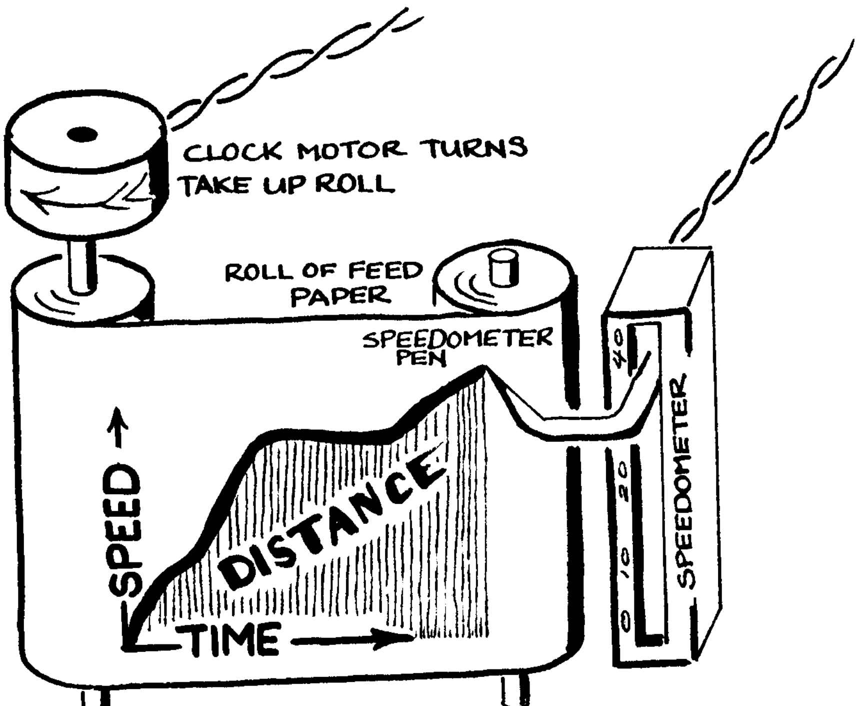
Yes, that is the answer, but that is not it. That is just some arithmetic. Arithmetic is blind. Can you visualize what you are doing? To visualize, use geometry. Geometry has eyes.

Make a graph showing the history of the ride. For one hour it is at five mph. Then it drops to four mph and stays there for three hours. Then it jumps up to seven mph for two hours and finally it drops to zero which means the bike stops.



Now split the graph into three rectangles. Each rectangle represents one segment of the trip. The first rectangle is 5 mph high and 1 hour wide. What is the area of this rectangle? Multiply its height by its width—that is, multiply 5 mph by 1 hour—and you get 5 miles. The area of the rectangle is the distance covered during the first segment of the ride. Likewise the area of the second rectangle is 4 mph multiplied by 3 hours which is 12 miles. So the area of each rectangle is equal to the distance traveled on that segment of the ride.

That gives you a nice way to visualize distance traveled. Imagine a recording speedometer that gives you a graph of your speed plotted against time. The total area under the speed curve must tell how far you have traveled.



RECORDING SPEEDOMETER

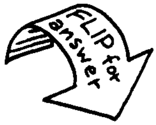
INTEGRAL CALCULUS

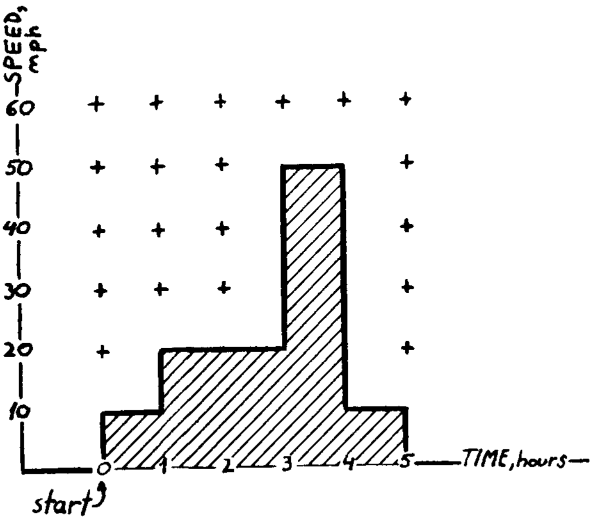
Look at the speed graph and then answer these questions. Two hours into the trip how fast was the thing going?

a) zero mph
b) 10 mph
c) 20 mph
d) 30 mph
e) 40 mph.

How far did the thing go during the whole trip?

a) 40 miles
b) 80 miles
c) 110 miles
d) 120 miles
e) 210 miles.





ANSWER: CALCULUS

The answer to the first question is c. Above the 2-hour mark the speed graph reads 20 mph.

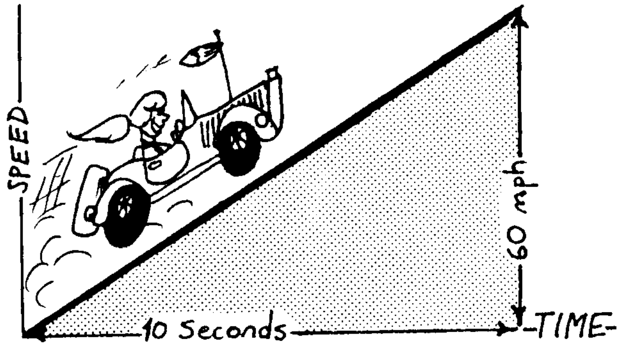
The answer to the second question is also c. The area under the speed line (or curve) is divided into little squares. Each square is 1 hour wide and 10 mph high. That means the area of each little square is 10 miles. Now count the little squares under the curve. There are eleven in all. Eleven times ten miles equals 110 miles. So the total area under the graph is 110 miles and that's how far the thing went during the whole trip. How can the area of a square represent miles? Must it not represent square miles? The area of a square represents square miles if its width and height are measured in miles, but if its width is measured in hours and its height in miles per hour, and you have imagination, its area is miles.

The technique you used here for finding the distance traveled is the technique of Integral Calculus. Integral means to integrate or sum many small parts. Calculus refers to many very small parts or layers which build up to make the sum. The name comes from minerals which build up in layers such as the calculus which builds up on your teeth. As the dentist scrapes it it flakes off. Each flake is a layer.

DRAGSTER

A dragster starts from rest and accelerates to 60 mph in 10 seconds. How far does it travel during those 10 seconds?

a) 1/60 mile
b) 1/12 mile
c) 1/10 mile
d) 1/2 mile
e) 60 miles.



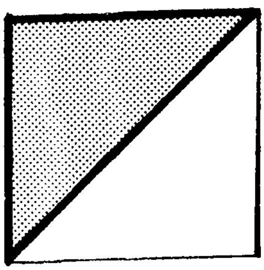
ANSWER: DRAGSTER

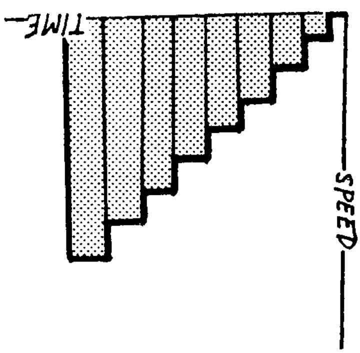
The answer is: b. First let's get everything in hours. Ten seconds is 1/6 of a minute and 1 minute is 1/60 of an hour, so 10 seconds is 1/360 of an hour.

The area under the speed line is a triangle and the area of a triangle is one-half of its height multiplied by its length. The triangle area is one-half the height multiplied by the length because the area of the triangle is half the area of the rectangle and the area of the rectangle is height mutiplied by length.

The height of the triangle is 60 mph and its length is 1/360 part of an hour so total distance moved must be (½) × (60 mph) × (1 hr/360) = 1/12 of a mile.

You can, if you want, think of the triangle as made up from a bunch of constant-speed steps. Each step is one layer of calculus.

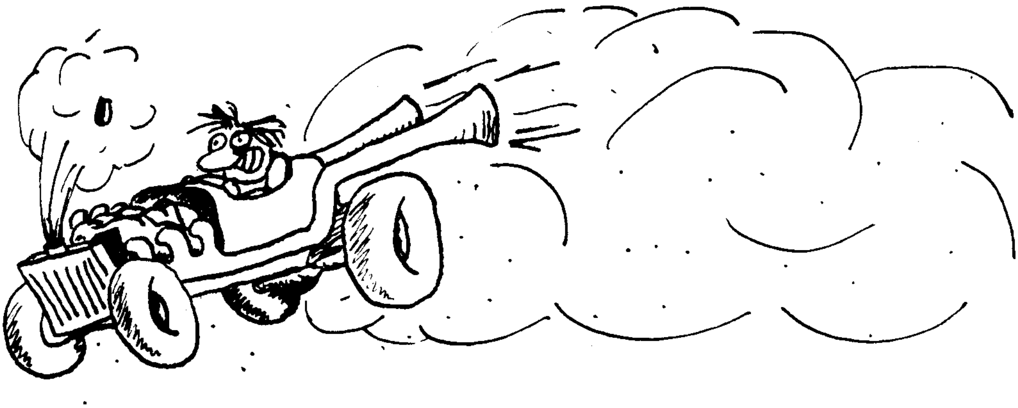




NO SPEEDOMETER

The next dragster is so stripped down that it does not even have a speedometer. At maximum acceleration from rest it goes 1/10 of a mile in 10 seconds. What speed did it get up to in those ten seconds?

a) 6 mph, b) 52 mph, c) 60 mph,
d) 62 mph, e) 72 mph.



ANSWER: NO SPEEDOMETER

The answer is: e. This is almost a rerun of DRAGSTER. The rule was: $(\frac{1}{2}) \times (\text{maximum speed}) \times (\text{time}) = (\text{distance})$.

So in this case $(\frac{1}{2}) \times (?\ \text{mph}) \times (1\ \text{hr}/360) = 1\ \text{mile}/10$.

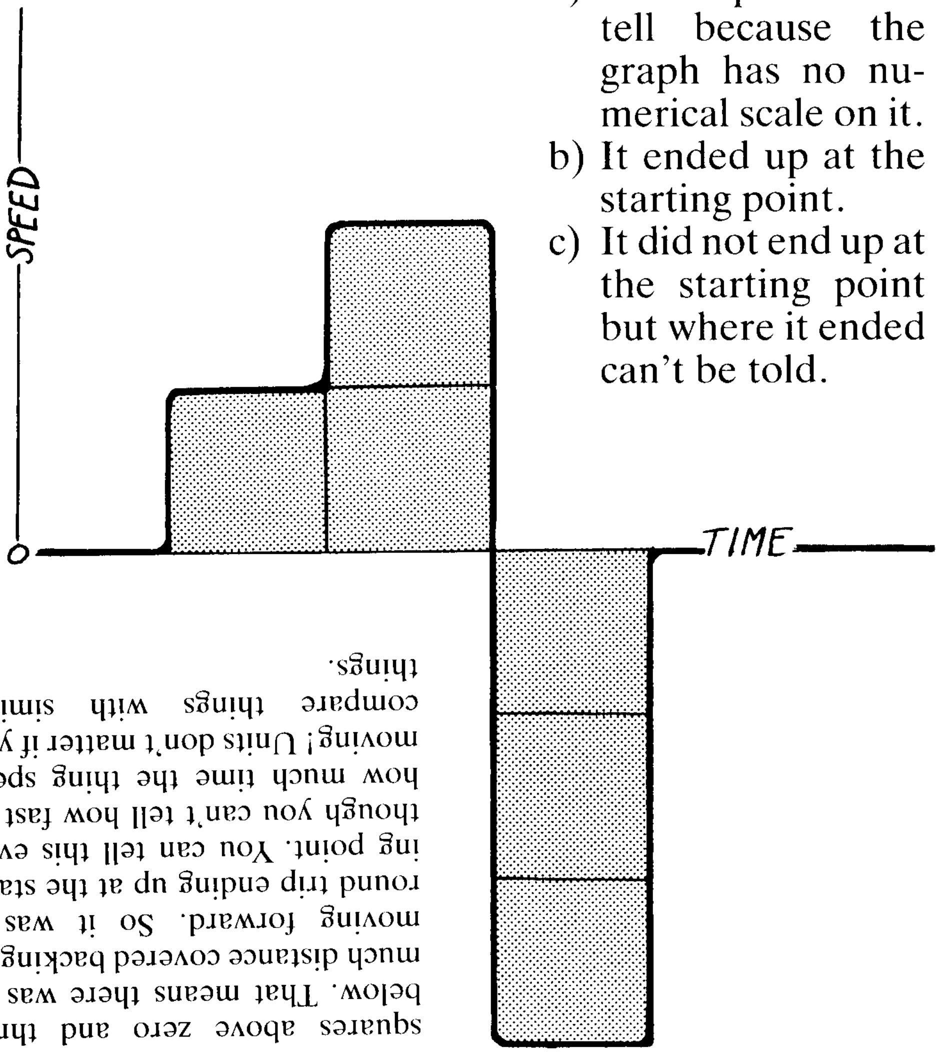
Divide both sides of this equation by 1 hr/360. Remember 1 hr/360 divided by 1 hr/360 equals one, and 1 mile/10 divided by 1 hr/360 equals 36 mph, so: $(1/2)(?\ \text{mph}) = 36\ \text{mph}$.

Finally: $?\ \text{mph} = (2) \times (36\ \text{mph}) = 72$ miles per hour.

NOT FAR

Look at this speed graph and tell how far away from the starting point this thing ended up.

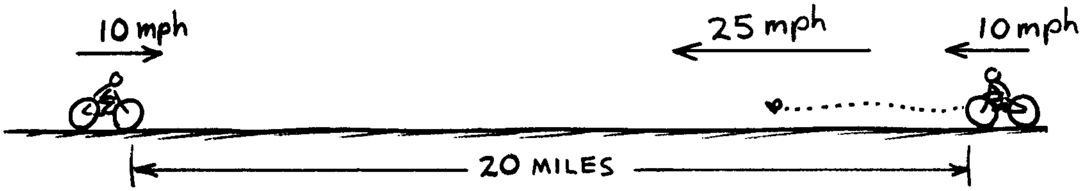
a) It is impossible to tell because the graph has no numerical scale on it.
b) It ended up at the starting point.
c) It did not end up at the starting point but where it ended can't be told.



ANSWER: NOT FAR

The answer is: b. What does it mean when the speed is less than zero? It means the thing is going backwards. Now there are three squares above zero and three below. That means there was as much distance covered backing as moving forward. So it was a round trip ending up at the starting point. You can tell this even though you can't tell how fast or how much time the thing spent moving! Units don't matter if you compare things with similar things.

THE BIKES AND THE BEE



Two bicyclists travel at a uniform speed of 10 mph toward each other. At the moment when they are 20 miles apart, a bumble bee flies from the front wheel of one of the bikes at a uniform speed of 25 mph directly to the wheel of the other bike. It touches it and turns around in a negligibly short time and returns at the same speed to the first bike, whereupon it touches the wheel and instantaneously turns around and repeats the back-and-forth trip over and over again — successive trips becoming shorter and shorter until the bikes collide and squash the unfortunate bee between the front wheels. What was the total mileage of the bee in its many back-and-forth trips from the time the bikes were 20 miles apart until its hapless end? (This can be very simple or very difficult, depending on your approach.)

a) 20 miles
b) 25 miles
c) 50 miles
d) More than 50 miles
e) This problem cannot be solved with the information given

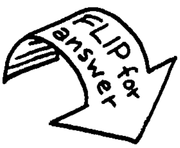
ANSWER: THE BIKES AND THE BEE

The answer is: b. The total mileage of the bee was 25 miles. The simplest approach to this solution is to consider the time involved. It will take the bicyclists an hour to meet, since each travels 10 miles at a speed of 10 mph — so the bee makes its many back-and-forth trips in an hour also. Since its speed is 25 mph, it travels a total distance of 25 miles. Again, time is an important consideration in velocity problems!

SAM

Dr. Pisani exercises his dog Sam on a 15-minute walk by throwing a stick that Sam chases and retrieves. To keep Sam running for the longest time as Dr. Pisani walks, which way should he throw the stick?

a) In front of him
b) In back of him
c) Sideways
d) In any direction, as all are equivalent



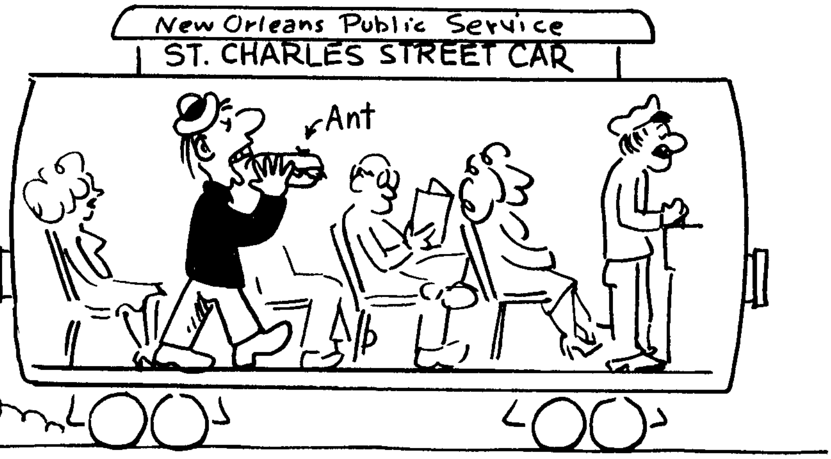
ANSWER: SAM

The answer is: d. Again, time is the important factor. Pisani is going to keep Sam running for 15 minutes regardless of which way he throws the stick! If the question asked for the most running time per throw, then the answer would be b, backward, because Sam would have to run the additional distance Pisani moved during his chase for the stick. But the question simply referred to Sam's running time during Pisani's 15-minute walk. Tricky? Perhaps — but there is a point here, and that is to be sure you're answering the question that is asked. How unfortunate that so many students taking exams often answer questions that are not really asked. Check yourself on this mishap when *you* take exams!

SPEED ON SPEED

The St. Charles Street streetcar is approaching Canal Street at 144 inches per second. A person in the streetcar is facing forward and walking forward in the car with a speed of 36 inches per second relative to the seats and things in the car. The person is also eating a Poor Boy which is entering his mouth at 2 inches per second (he eats fast). An ant on the Poor Boy is running to the end of the Poor Boy, away from the person's mouth. The distance between the ant and the end of the Poor Boy towards which it is running is closing at 1 inch per second. Now the question is: How fast is the ant approaching Canal Street?

a) Zero in/s
b) 100 in/s
c) 170 in/s
d) 179 in/s
e) 180 in/s



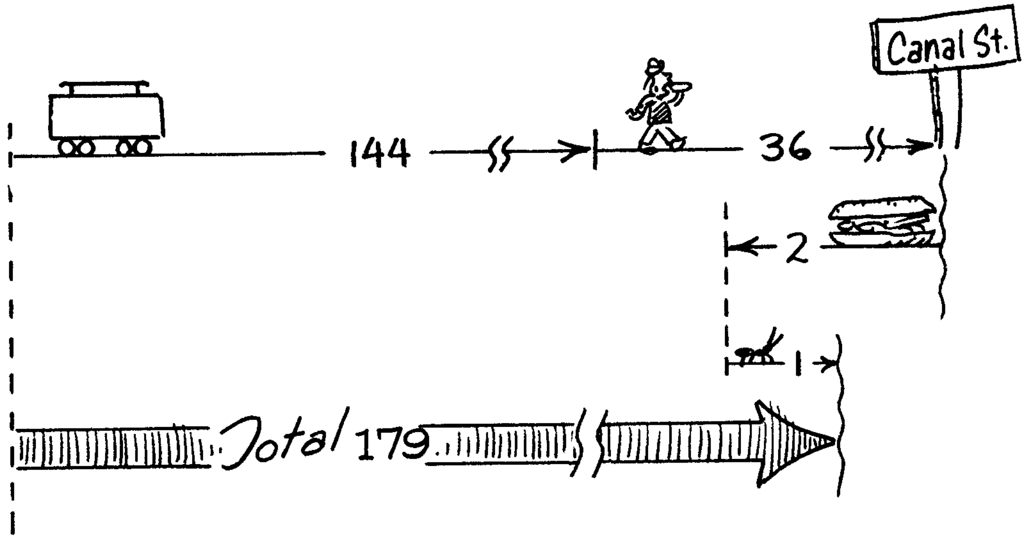
Could you convert your above answer from inches per second to miles per hour? (You don't need to do the actual arithmetical calculation.)

a) Yes   b) No

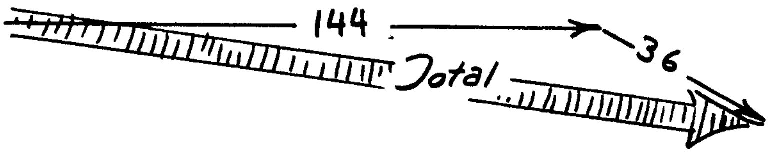
If you answered "Yes" to the above, ask yourself how it is possible to say *anything* about how far the ant goes in an *hour* since the poor ant is eaten and dead in a matter of seconds.

ANSWER: SPEED ON SPEED

The answer to the first question is: d. You can picture it like this. Add the speed of the street car to the speed of the person — both going toward Canal Street. Subtract the speed of the Poor Boy sandwich (which is going the other way). Then add the speed of the ant (which is also going toward Canal Street).



This same idea can be used to add speeds which are not back and forth in the same direction. For example, if the person walks at an angle inside the street car (forget the Poor Boy & ant).

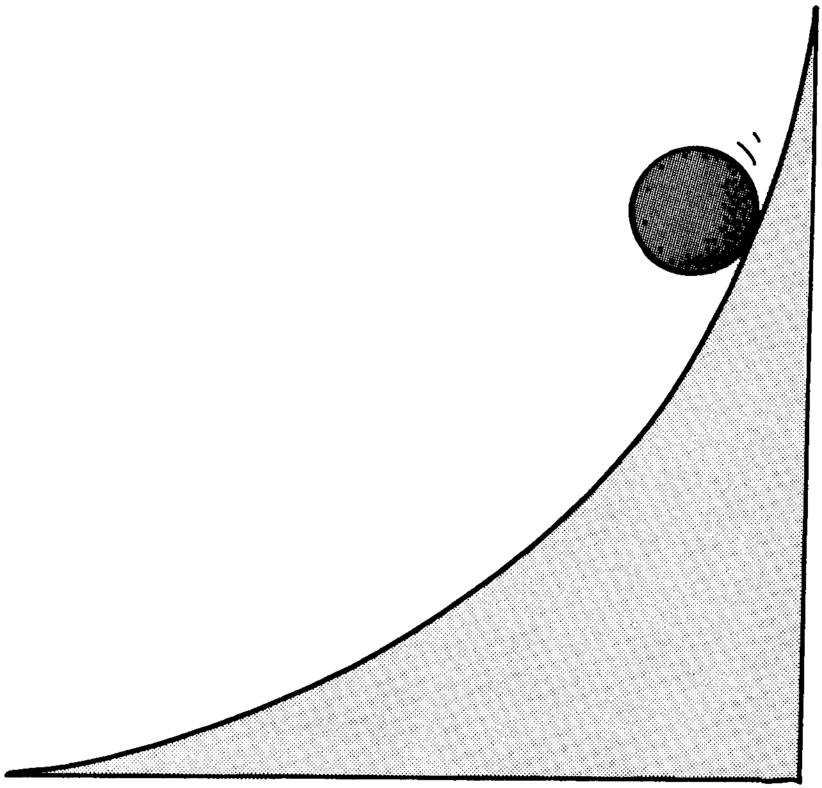


The answer to the second question is: a. You must remember, however, that when you speak of miles per hour you are making a CONDITIONAL statement. You are not saying how far a thing *will* go, but how far it *would* go IF it could go for one hour.

SPEED AIN'T ACCELERATION

As the ball rolls down this hill

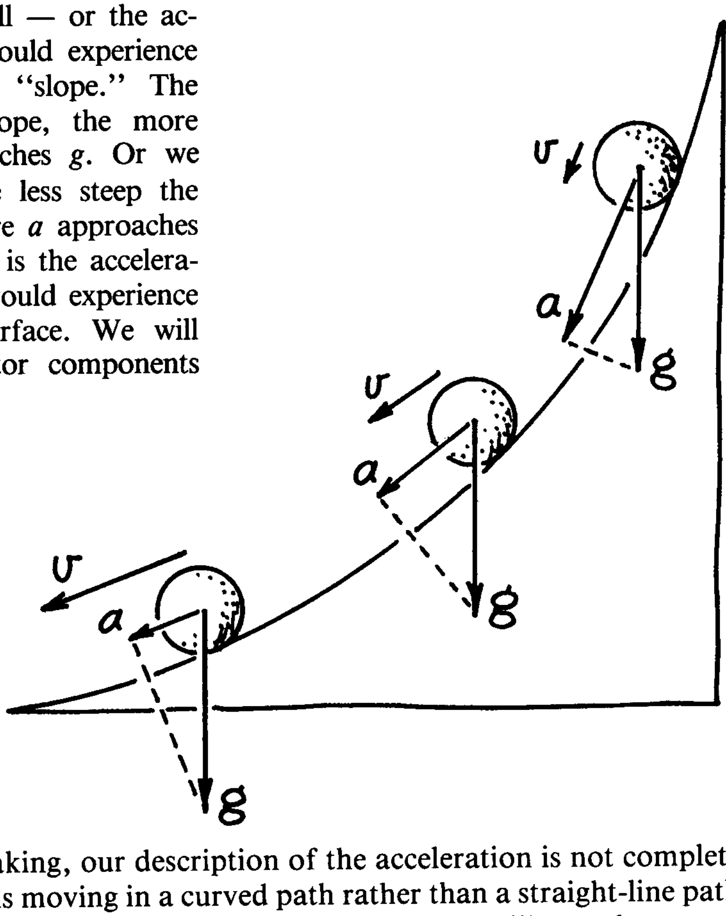
a) its speed increases and acceleration decreases
b) its speed decreases and acceleration increases
c) both increase
d) both remain constant
e) both decrease



ANSWER: SPEED AIN'T ACCELERATION

The answer is: a. The speed of the ball increases as it goes down the hill, but its acceleration depends on how steep the hill is. At the top of the hill the acceleration is greatest because the hill is steepest, and as the ball goes down, the hill is less steep so the ball's acceleration decreases. So acceleration can decrease at the same time speed is increasing. Store this example in your memory and recall it if you forget the difference between speed and acceleration.

In the sketch we show the acceleration of the ball *a* parallel to the surface as a component of *g*, the acceleration of free fall — or the acceleration it would experience on a vertical "slope." The steeper the slope, the more that *a* approaches *g*. Or we could say, the less steep the slope, the more *a* approaches zero — which is the acceleration the ball would experience on a level surface. We will return to vector components later.



Strictly speaking, our description of the acceleration is not complete. Since the ball is moving in a curved path rather than a straight-line path, the curved motion involves another effect that we will treat later.

ACCELERATION AT THE TOP

A stone is thrown straight upward and at the tippity top of its path its velocity is momentarily zero. What is its acceleration at this point?

a) Zero
b) 32 ft/s^2
c) Greater than zero, but less than 32 ft/s^2

ANSWER: ACCELERATION AT THE TOP

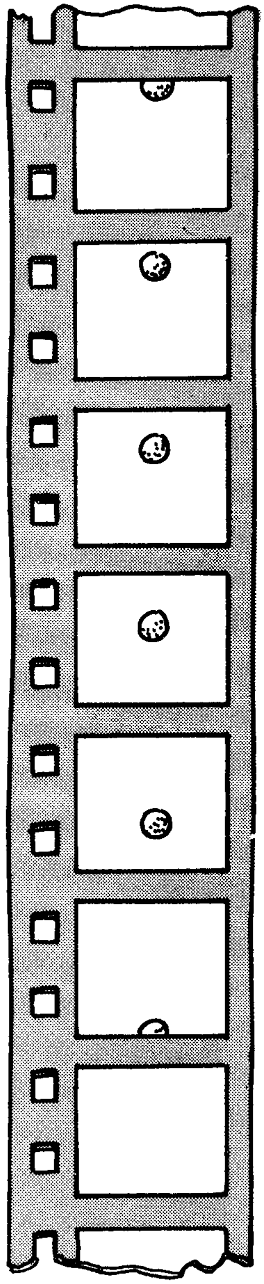
The answer is: b. Although its velocity is instantaneously zero, it is still undergoing a RATE of *change* of velocity. This is evident if you consider its motion a moment before or after, in which case the stone is moving. For example, a second before or after reaching the top, its velocity is 32 ft/s. So it is undergoing a rate of change as it passes through the zero value of velocity just as it is undergoing the same rate of change passing through any other value of velocity. If air resistance is negligible, this rate of change of velocity is 32 ft/s^2.

Or from another point of view — Newton's 2nd Law states that an impressed net force on any object will accelerate that object. Gravitation acts on the stone at all points in its path, producing a constant acceleration at all points in its path — which includes the tippity top! After all, if the ball were momentarily stationary at the top and NOT accelerating, then it would remain stationary, which means it would not fall — ever.

TIME REVERSAL

A motion picture film is made of a falling object which shows the object accelerating downwards. Now if the film is run backwards, it will show the object accelerating

a) upward
b) still downward



ANSWER: TIME REVERSAL

Surprise! The answer is: b. If the film is run backwards it will show the object moving up, but its acceleration will still be downward. Run the film backwards in your head. The ball is seen moving upwards initially fast, and then more slowly, just as if you threw it upward. Clearly the upward motion is not increasing so it could not be accelerating upwards. But the speed is changing so it is accelerating, and a decrease of upward speed is a downward acceleration.

What this goes to show is something about rates of change. If time is reversed the rate of change of anything will reverse, that is the rate of change of anything will decrease if it was previously increasing. But if time is reversed the rate of change of the rate of anything will not reverse. Acceleration is the rate of change of velocity and velocity is the rate of change of position so acceleration is a rate of change of a rate of change and that is why it did not reverse.

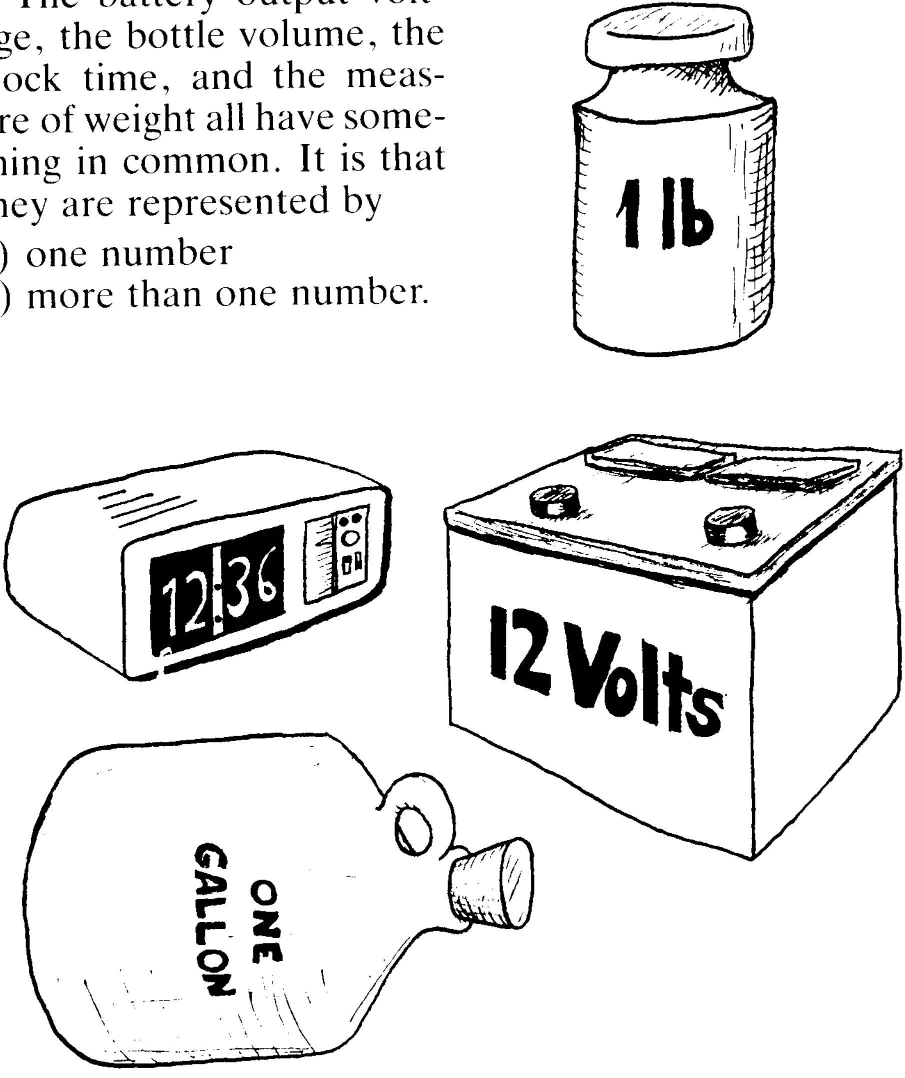
What about a rate of change of a rate of change of a rate of change — does it reverse when time reverses? Yes, it does reverse. What about the rate of change of the rate of change of the rate of change of the rate of change? It does not reverse when time reverses. Incidentally, there are symbols to represent these things which save a lot of words.

If X is the position of a thing then $\dot{X}$ is the rate of change of position or speed of the thing, and $\ddot{X}$ is the acceleration of the thing, and $\dddot{X}$ is the rate of change of the acceleration which is called the jerk, and $\ddddot{X}$ is the rate of change of the jerk which perhaps you can think up a good name for.

SCALAR

The battery output voltage, the bottle volume, the clock time, and the measure of weight all have something in common. It is that they are represented by

a) one number
b) more than one number.



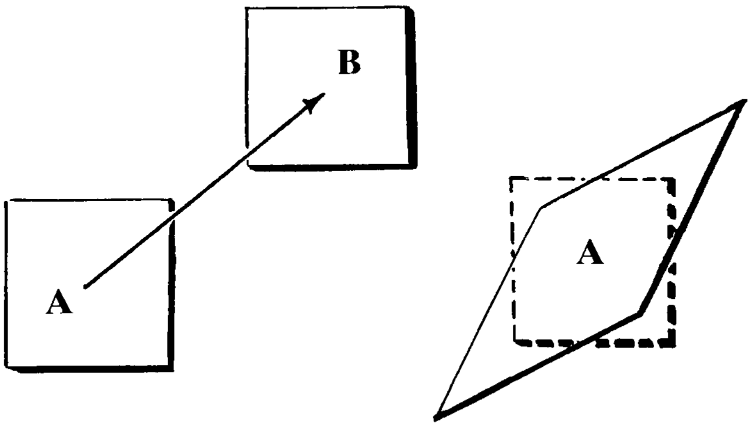
ANSWER: SCALAR

The answer is: a. Each is represented by only one number—the battery by 12 volts, the bottle by one gallon, the time by 12:36 and the weight by one pound. Things described by one number are called scalars. For example: on a scale of one to ten, how do you rate this teacher?

TENSOR

Suppose you have a little rubber square. If the square was simply moved from place A to B that change could be easily expressed as a vector. But suppose the little square is not moved. Suppose it is left at A. At A the little rubber square is pulled into the shape of a parallelogram. That change from square to parallelogram can be easily represented as a

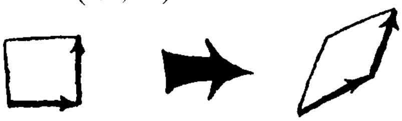
a) scalar
b) vector
c) neither



ANSWER: TENSOR

The answer is: c. There are things which cannot easily be represented as scalars or vectors—for example, the parallelogram. But parallelograms can be represented as things called TENSORS. The name comes from the tension that deformed the square into the parallelogram shape. A tensor is a super vector. A regular vector is made up from a string of scalars like (3, 5, 6,). The three, the five, and the six are by themselves each just scalars. A super vector is also made up from a string of things, but the things in the string are not scalars; each thing in the string is itself a vector. That is why I call a tensor a super vector. So a tensor must look like this: (→, ↗, →), a string of vectors.

How many vectors does it take to represent a parallelogram? Well, how many sides does a parallelogram have? Four. But you only need to know two because opposite sides of a parallelogram are parallel—that's why a parallelogram is called a parallelogram. So a parallelogram can be represented by a tensor, which is made of two vectors. For example a square (which is a parallelogram) is represented by this tensor: $(\uparrow, \rightarrow)$. When the square is pulled out of the square shape it is represented by this tensor $(\nearrow, \nearrow)$.



Now each vector can be represented by a string of scalar numbers and that string can be written in a column rather than a row

$$\begin{pmatrix} 3 \\ 5 \\ 6 \end{pmatrix} \text{ in place of } (3, 5, 6)$$

So a tensor can be written like this $\left[\begin{pmatrix} 3 \\ 5 \\ 6 \end{pmatrix}, \begin{pmatrix} a \\ b \\ c \end{pmatrix}, \begin{pmatrix} g \\ h \\ i \end{pmatrix}\right]$

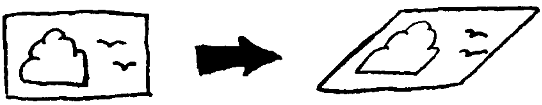
where $\begin{pmatrix} a \\ b \\ c \end{pmatrix}$

and $\begin{pmatrix} g \\ h \\ i \end{pmatrix}$

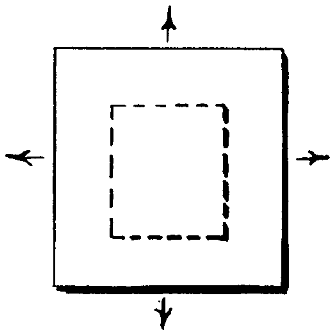
are other vectors.

This 3×3 tensor must represent some sort of strained cube. The cube has three edges, each edge represented by a three-dimensional vector.

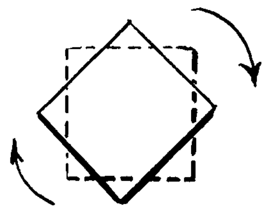
As you might expect, tensors are very useful to structural engineers. They represent practical things like shear strain, rotation, expansion, and deviation. You often see tensor transformations in the clouds. This happens because the wind speed aloft exceeds the wind speed near the ground, so a cubical mass of atmosphere is sheared and any cloud embedded in it is also sheared.



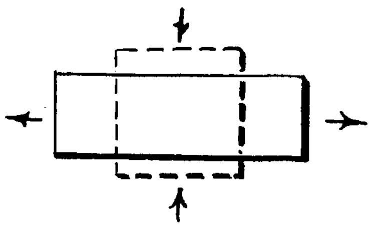
tensor transform of a cloud by wind shear



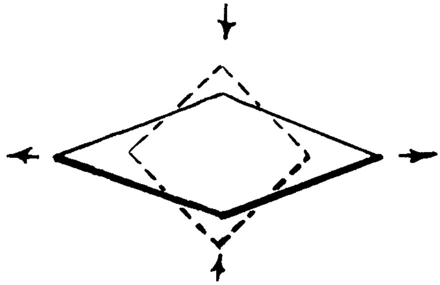
expansion



rotation

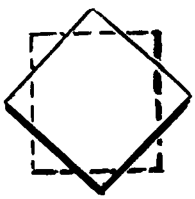


deviation

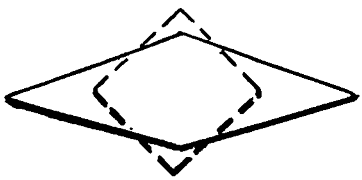


deviation

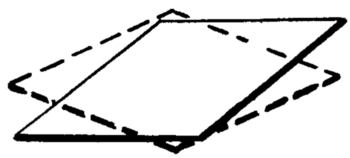
All tensor transformations can be represented as combinations of expansions, rotations, and deviations. Here, for example, a square is sheared into a parallelogram by means of a rotation, deviation, and counter-rotation.



rotation



deviation



counter-rotation

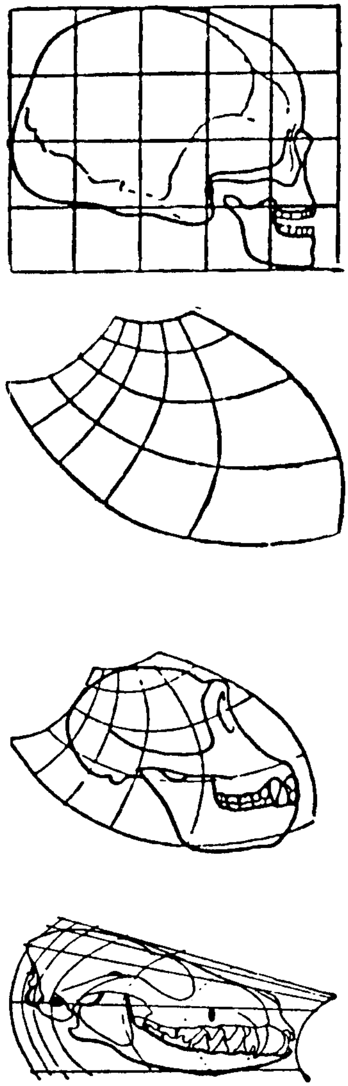
ANSWER: SUPER TENSORS

The answer is: a. The super tensor is a vector that is made of a string of ordinary tensors. Do super super tensors exist? Yes, they are vectors made of a string of super tensors, and on and on you can go.

Can you give an example of something that can be represented by a super tensor? Yes, the transformation of a human skull into the skull of a baboon or dog can be represented as a super tensor. Each square in the skull transforms into a parallelogram having a different shape. Since each parallelogram is different, this transformation can't be described by an ordinary tensor, which simply transforms a square into one parallelogram. More than one simple tensor is needed—a whole bunch of different tensors are needed, and a super tensor is a string of ordinary tensors. Ordinary tensors can change the direction and length of straight lines; super tensors can change straight lines into curved lines, as well as change their direction and length. Ordinary tensors cannot curve straight lines.

The equations in Einstein's General Theory of Relativity are written in terms of super tensors. Gravity, which is described by the theory, curves the paths of objects, paths that in the absence of gravity would be straight lines. And some attempts to make Unified Field Theories, which combine gravity, electricity, and other forces into one thing, are based on super super tensors.

Textbooks refer to these higher tensors as third- and fourth-order tensors. These books sometimes call scalars zeroth-order tensors.



SUPER TENSORS

Do super tensors exist? a) Yes. b) No.

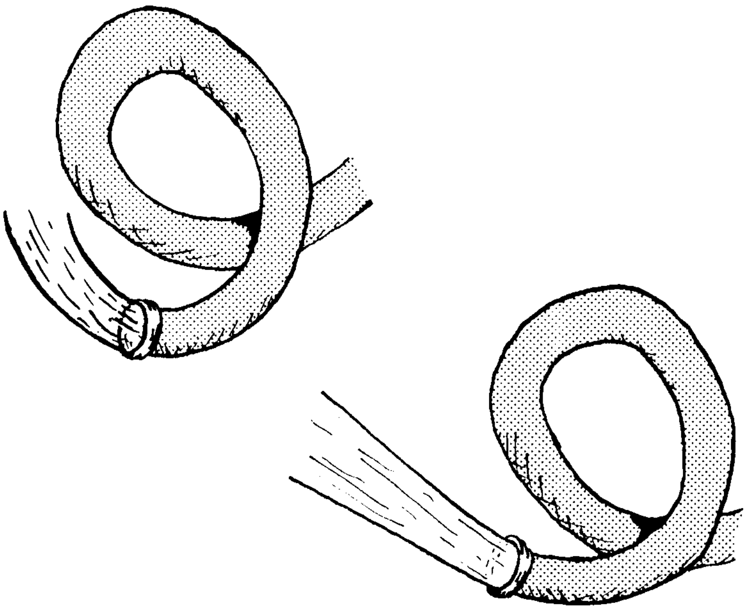
KINK

Water is shooting out of the end of a pipe. The end of the pipe is bent into a figure 6.

a) The water shoots out in a curved arc

b) The water shoots out in a straight line

Forget about the effect of gravity.



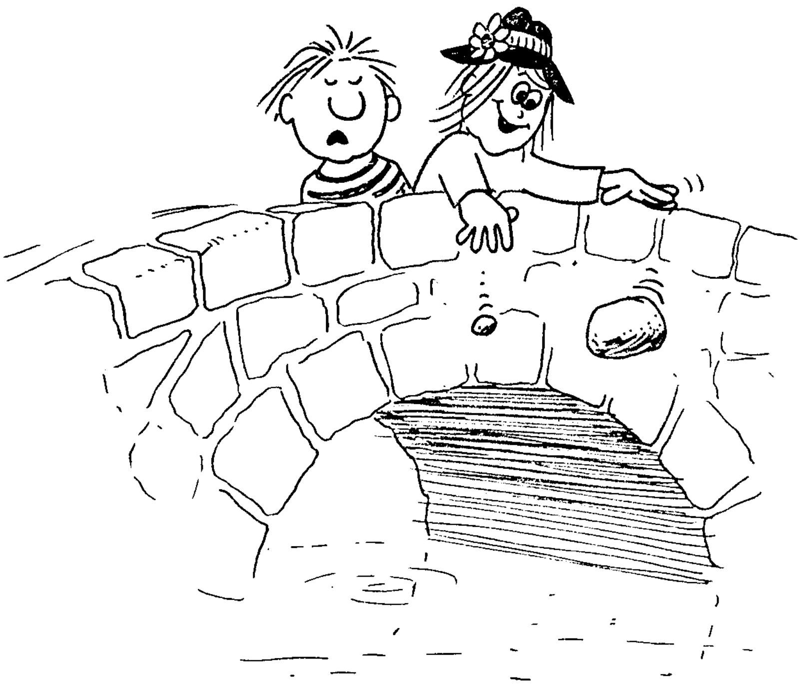
ANSWER: KINK

The answer is: b. Once out of the pipe the water goes in a straight line. Force is required to bend the water's path. If the water is inside the pipe then the pipe can force it to flow in a kinked path. But when the water gets outside it is free. Free things move in straight lines.

FALLING ROCKS

A boulder is many times heavier than a pebble — that is, the gravitational force that acts on a boulder is many times that which acts on the pebble. Yet if you drop a boulder and a pebble at the same time, they will fall together with equal accelerations (neglecting air resistance). The principal reason the heavier boulder doesn't accelerate more than the pebble has to do with

a) energy
b) weight
c) inertia
d) surface area
e) none of these

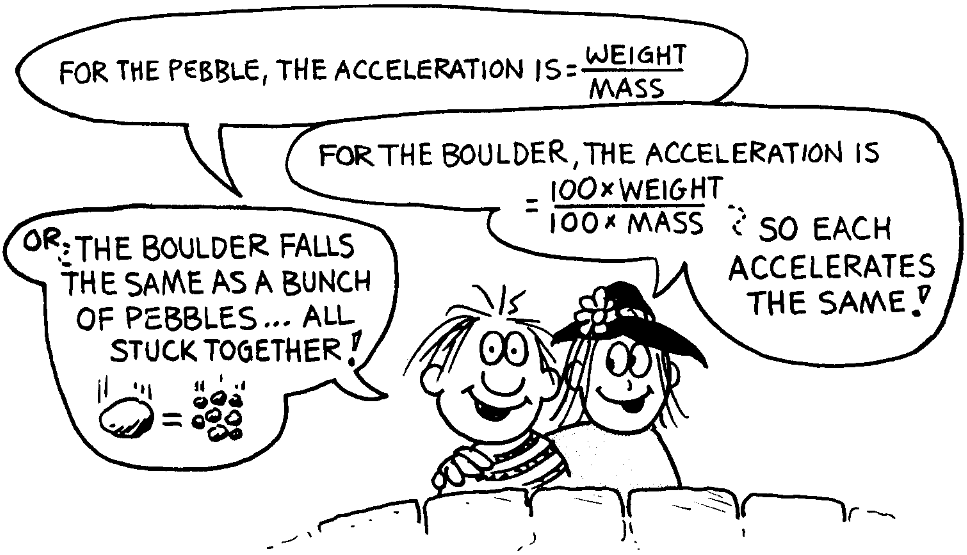


ANSWER: FALLING ROCKS

The answer is: c. It is inertia pure and simple.

If acceleration were proportional only to force, then the larger force of gravity acting on the boulder would result in it out-accelerating the lighter pebble. But the acceleration of an object also has to do with its mass — with its inertia — with its tendency to resist a change in motion. Mass resists acceleration — the greater the mass for a given force, the less the resulting acceleration. This is Newton's 2nd Law: Acceleration is directly proportional to net force and inversely proportional to mass; i.e. $a = \frac{F}{m}$. For a freely falling object, the only force acting on it is that of gravity — its weight. And weight is proportional to mass (two kilograms of sugar have twice the weight of one kilogram). A boulder that weighs 100 times more than a pebble also has 100 times the mass. It may be pulled by gravity with a force 100 times greater than that for the pebble, but it has 100 times the inertia, or 100 times the reluctance to change its state of motion.

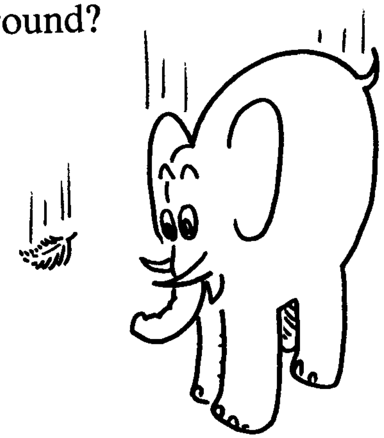
So we see there is a reason why the ratio of force/mass and therefore the acceleration is the same (32 ft/s^2) for all freely falling objects! When air resistance is not negligible (next question), then the acceleration of fall is less than 32 ft/s^2. If air resistance builds up to the weight of the falling object, then the net force is zero and there is no acceleration.



THE ELEPHANT AND THE FEATHER

Suppose that both an elephant and a feather fall from a high tree. Which encounters the greatest force of air resistance in falling to the ground?

a) The elephant
b) The feather
c) Both the same



ANSWER: THE ELEPHANT AND THE FEATHER

The answer is: a. Note that although the EFFECTS of air resistance against the feather are more pronounced, the actual FORCE of air resistance against the falling elephant is many times greater than the force against the feather. This is because the larger elephant plows through considerably more air than does the smaller feather. Also, the heavier elephant falls faster through the air, increasing air resistance even more. The feather is very light, perhaps a fraction of an ounce, so doesn't fall very fast before the air resistance it encounters builds up to the same fraction of an ounce. When this happens the feather reaches its terminal velocity — acceleration terminates and the velocity and air resistance remain unchanged throughout the remainder of the fall. An elephant falling from a high tree, on the other hand, encounters air resistance that builds up to say 20 pounds — Much greater than that of the feather, but practically negligible compared to the 2-or-so-ton unfortunate elephant who accelerates all the way to the ground.

If you answered this question incorrectly it is probably because you did not really answer the question that was asked. Be careful about distinguishing between that which is asked for and the EFFECT of that which is asked for. We'll have more such questions, so stay on your toes!

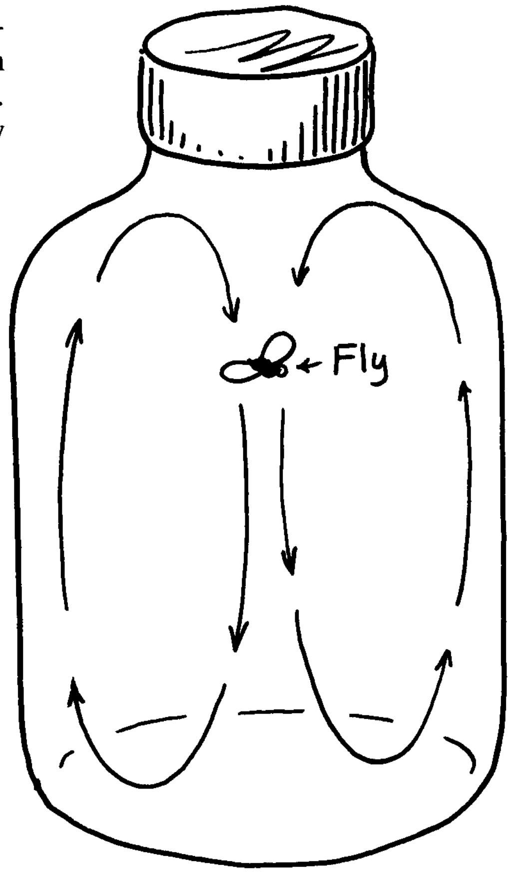
JAR OF FLIES

A bunch of flies are in a capped jar. You place the jar on a scale. The scale will register the most weight when the flies are

a) sitting on the bottom of the jar
b) flying around inside the jar
c) . . . weight of the jar is the same in both cases

ANSWER: JAR OF FLIES

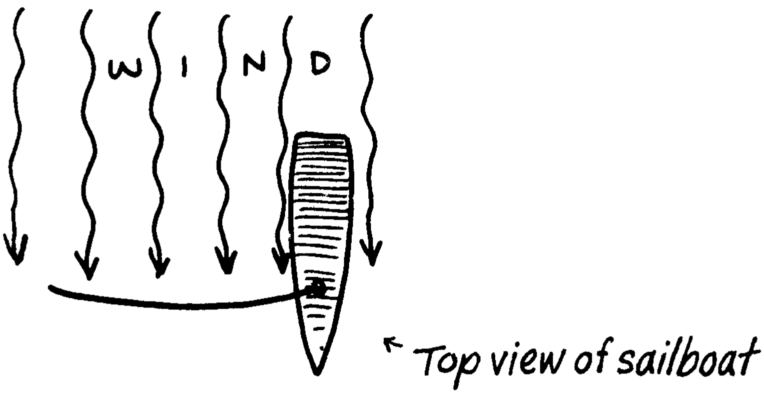
The answer is: c. When the flies take off or land there might be a slight change in the weight of the jar, but if they just fly around inside a capped jar the weight of the jar is identical to the weight it would have if they sat on the bottom. The weight depends on the mass in the jar and that does not change. But how is a fly's weight transmitted to the bottom of the jar? By air currents, specifically, the downdraft generated by the fly's wings. But that downdraft of air must also come up again. Does the air current not exert the same force on the top of the capped jar as on the bottom? No. The air exerts more force on the bottom because it is going faster when it hits the bottom. What slows the air down before it hits the top? Friction. Without air friction the fly could not fly.



WITH THE WIND

Everyone loves a sailboat, especially on a windy day. Suppose you are sailing directly downwind with your sails full in a 20 mph wind. Then the maximum speed you could hope to attain would be

a) nearly 20 mph
b) between about 20 and 40 mph
c) . . . there would be no theoretical speed limit in this case



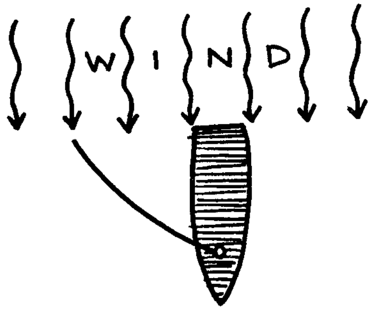
ANSWER: WITH THE WIND

The answer is: a. You could only attain the speed of the wind if the forces of water friction on the boat were zero — and even in this case you could not sail faster than the wind. Why? Because if the boat were travelling as fast as the wind there would no longer be any impact of air against the sail. The sail would sag as it would on a windless day. At the speed of the wind, there would be no wind relative to the sail.

AGAIN WITH THE WIND

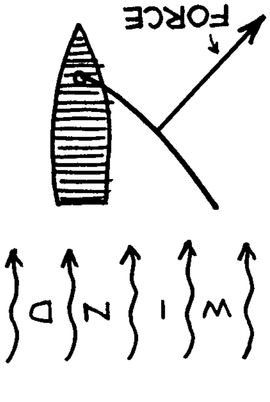
You are again sailing downwind and you pull your sail in so that it no longer makes a 90° angle with the keel of the boat. This tactic will

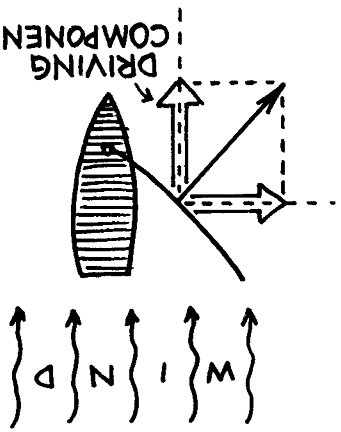
a) decrease the speed of the boat
b) increase the speed of the boat
c) not affect the speed of the boat



ANSWER:
AGAIN WITH THE WIND

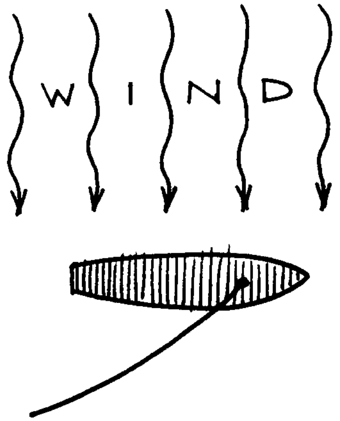
The answer is: a, for two reasons. First, the impact against the sail is less because the sail catches less wind in the angular position. Second, the direction of the wind impact force is not in the direction of the boat's motion. We find that whenever any fluid, be it gas or liquid, interacts with a smooth surface, the force of interaction is perpendicular to the smooth surface. So the vector arrow representing this force juts 90° from the surface of the sail, as shown. Not only is this vector smaller than for the case where the sail catches maximum wind as in the last question, but only a fraction of this vector is directed along the direction of the boat's motion. It is this component that drives the boat forward. (The component that is sideways to the boat's motion tends only to tip the boat and does not contribute to forward motion.) So the boat is pushed forward by the wind, but with not as much force as before. As the sail is pulled further in, the force vector decreases in magnitude and a smaller driving component results. When the sail is pulled all the way in, so that it is parallel to the keel, it catches no wind at all and the driving force is zero.



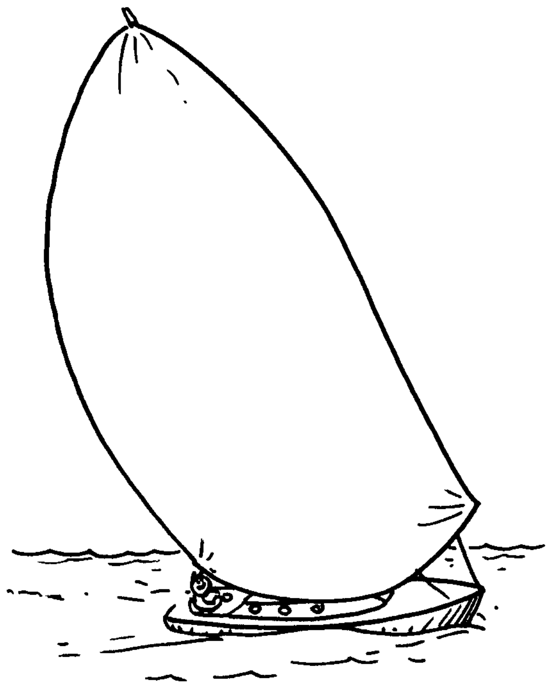


CROSSWIND

Keeping the angle of sail relative to the boat the same as in the last question, suppose you now direct your boat so that it sails directly across wind, rather than directly with the wind. Will you sail faster or slower than before?

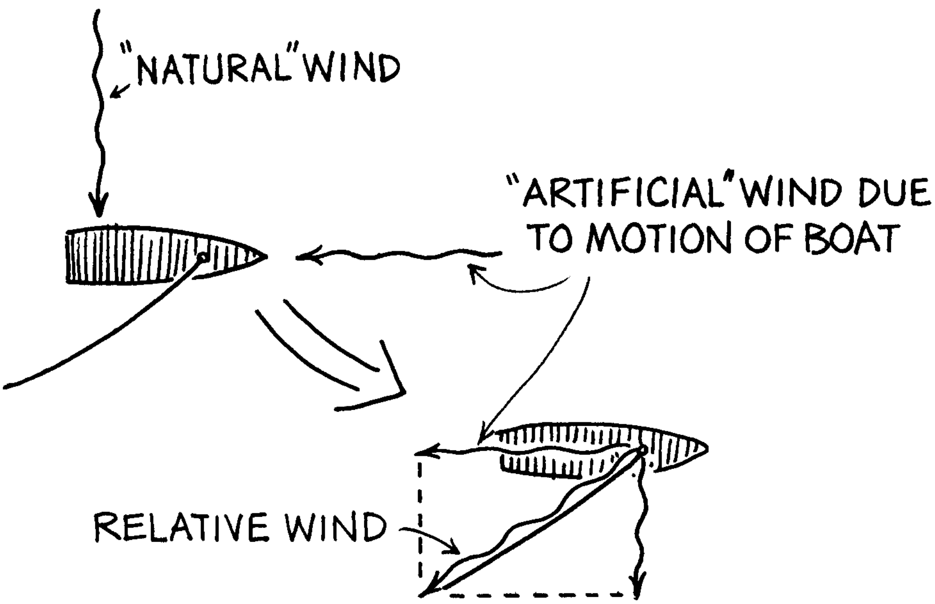


a) Faster
b) Slower
c) The same



ANSWER: CROSSWIND

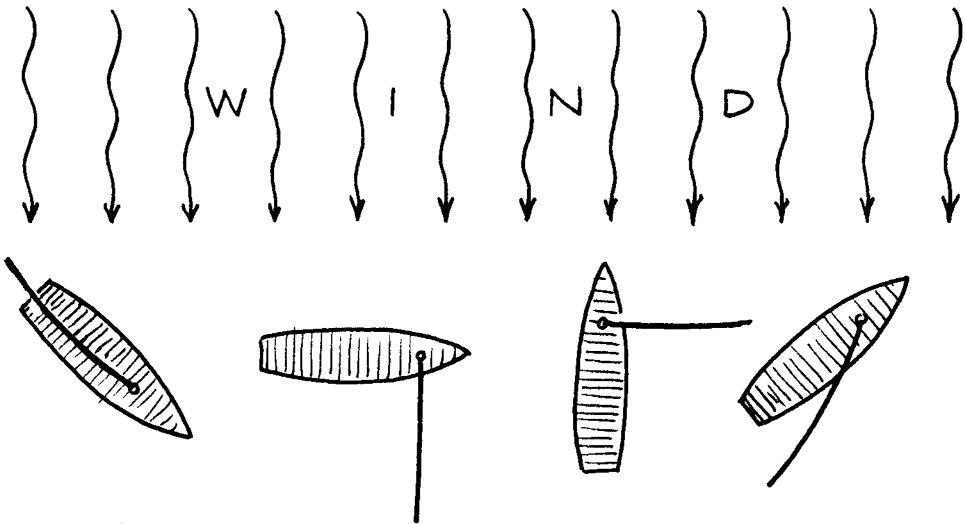
The answer is a. As before, the force vector perpendicular to the surface of the sail can be broken into components — one along the direction in which the boat can move, which drives the boat, and the other which is perpendicular to the boat's motion and is useless. Now, if the principal force vector in this case (wind impact against the sail) were no greater than before, the speed of the boat would be the same. But the force vector IS greater. Why? Because the sail doesn't catch up with wind speed so it will not eventually sag like before. Even when the boat is travelling as fast as the wind, there is an impact of wind against the sail. This drives the boat even faster, so it can sail faster than the wind in this position. It reaches its terminal speed when the "relative wind" (the resultant of the "natural" wind and the "artifical" wind due to the boat's motion) blows along the sail without making impact.



WHEN ANGLE OF RELATIVE WIND IS THE SAME AS THE SAIL ANGLE, WIND IMPACT IS NO MORE -

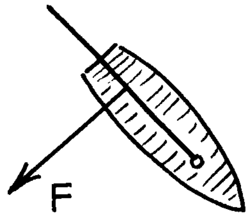
AGAINST THE WIND

This question is to employ your understanding of the 3 previous questions. For the four boats shown note the orientations of the sails with respect to both wind and keel directions. Which of these boats moves in a forward direction with the greatest speed?

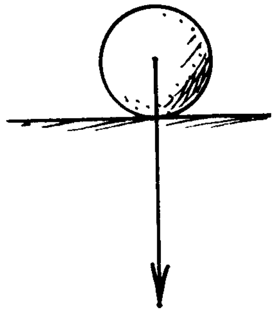


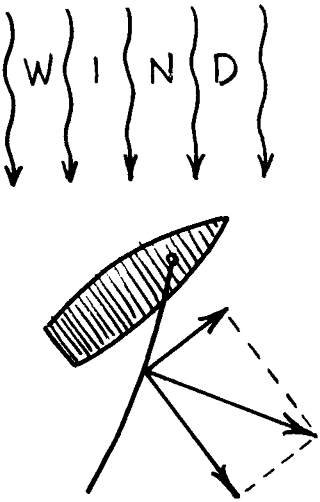
a) b) c) d)

ANSWER: AGAINST THE WIND



The answer is: d. It is the only boat that moves in a forward direction. The orientation of the sail for boat "a" is such that the force vector is perpendicular to the direction in which the boat can freely move (as dictated by the fin-like keel beneath). This completely sideways force has no component in a forward (or backward) direction. It is as useless in propelling the boat forward as the downward force of gravity is in pushing a bowling ball across a level surface. Sailboat "b" misses wind impact altogether, as the wind simply blows by the sail rather than into it. The sail of sailboat "c" receives full wind impact, but blows it backward rather than forward. The situation of "d" is not unlike that of the CROSSWIND question.



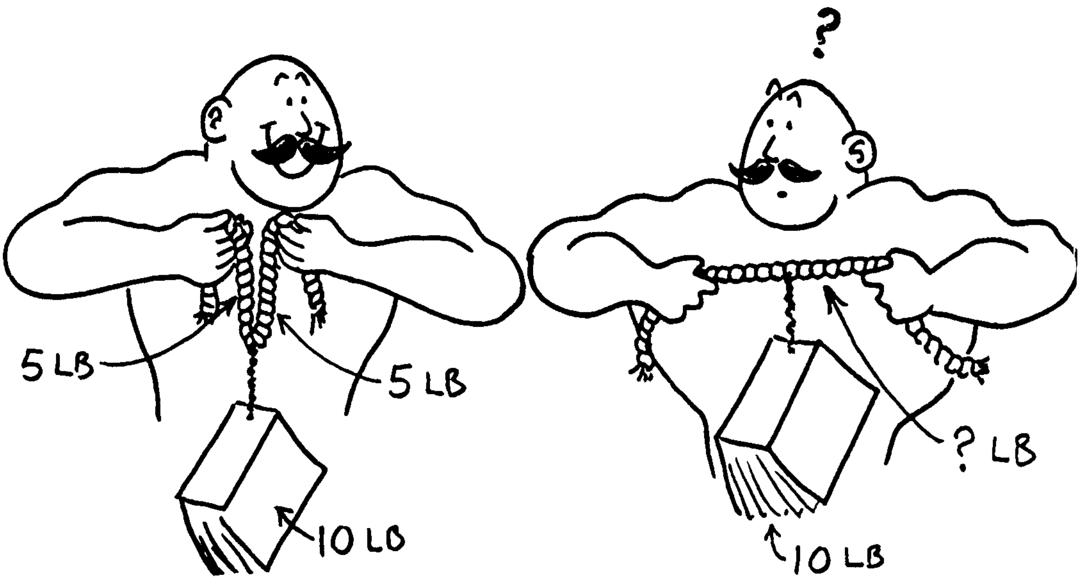


Note in the sketch that the force vector has a component along the forward direction which propels the boat at the indicated angle into and against the wind. This boat can actually sail faster than the crosswind sailboat, for the faster it travels, the GREATER is the force of the wind impact. So a sailboat's maximum speed is usually at an angle upwind! It cannot sail directly into the wind, so to reach a destination straight upwind it zigzags back and forth. This is called "tacking."

STRONGMAN

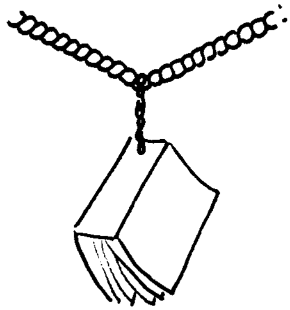
When the strongman suspends the 10-lb telephone book with the rope held vertically the tension in each strand of rope is 5 lbs. If the strongman could suspend the book from the strands pulled horizontally as shown, the tension in each strand would be

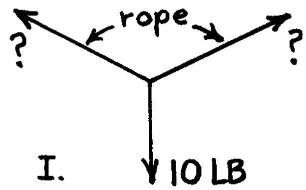
a) about 5 lbs
b) about 10 lbs
c) about 20 lbs
d) more than a million lbs



ANSWER: STRONGMAN

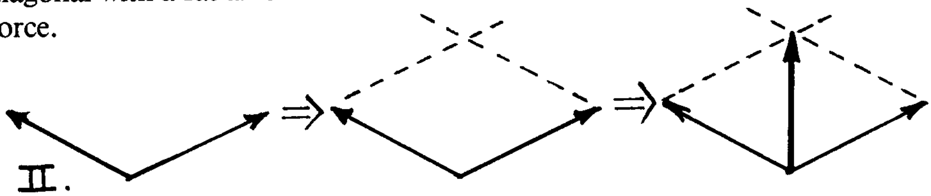
The answer is: d. To see why, consider the book suspended by the rope at the angle shown. We represent all the forces acting on the book with vector arrows. The 10-lb vector represents the weight of the book and acts straight downward toward the center of the earth. The length of this vector sets our scale of 10 lbs. Now, how long are the other vectors to keep the book in equilibrium? The size of these vector arrows compared to our 10-lb arrow will tell us what the tensions are in the rope.





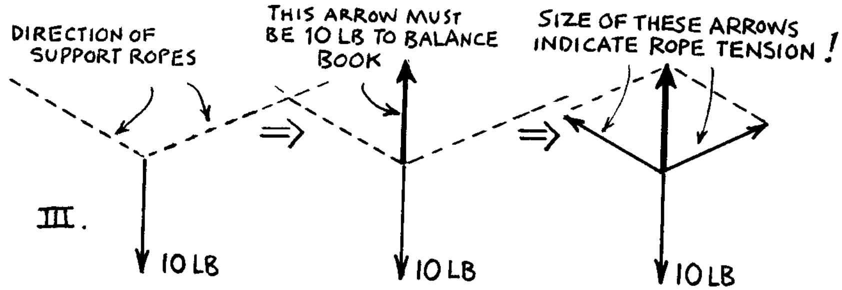
I.

Whenever two forces act together, the total effect of the two forces can be found using the following procedure: First, draw the two forces as thin arrows (sketch II). Then complete the parallelogram with dotted lines. Now, draw in the diagonal with a fat arrow. The fat arrow is the net force.


II.

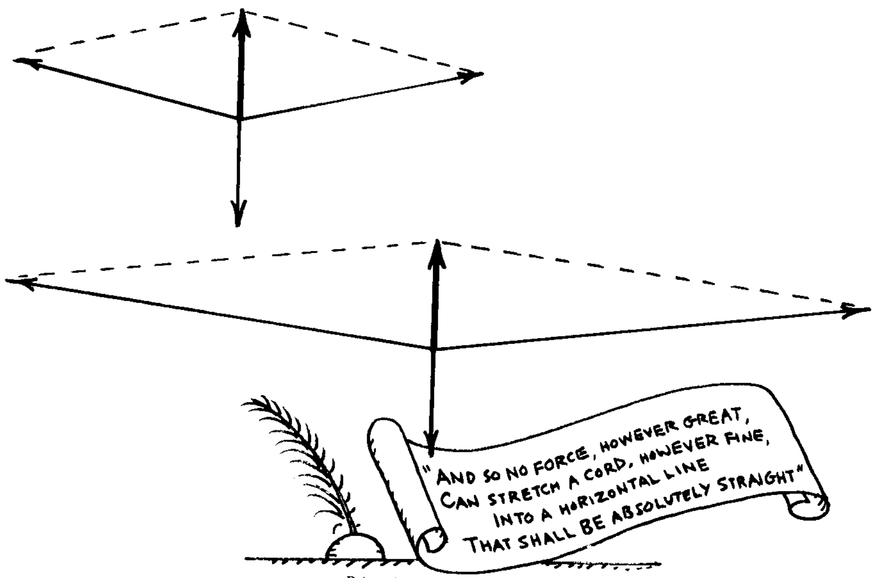
Incidentally, a physics teacher named Dave Wall says that some people think that if you pull on something with a longer rope, you should draw a longer force arrow. But that is the wrong way to think. The length of the force arrow depends only on how strong the force is — and that depends on how hard you pull — and has nothing to do with the rope length.

The total effect of the suspended ropes is to hold the 10-lb book up. That means the total effect of the ropes is an upward force of 10 lbs. How much force must the ropes exert to produce an upward force of 10 lbs? To find this force, first draw two lines extending out in the direction of the ropes (sketch III). Draw the 10-lb upward force you want the ropes to produce (fat arrow). Then draw two dotted lines from the tip of the 10-lb fat arrow so as to form a parallelogram with the ropes. Where the dotted lines hit the ropes, draw arrowheads. The arrows you have just drawn running along the ropes represents the force exerted by the ropes. As you can see, each of the rope arrows is longer and therefore represents more force than the 10-lb arrow. You can estimate the force by comparing the length of the arrows to



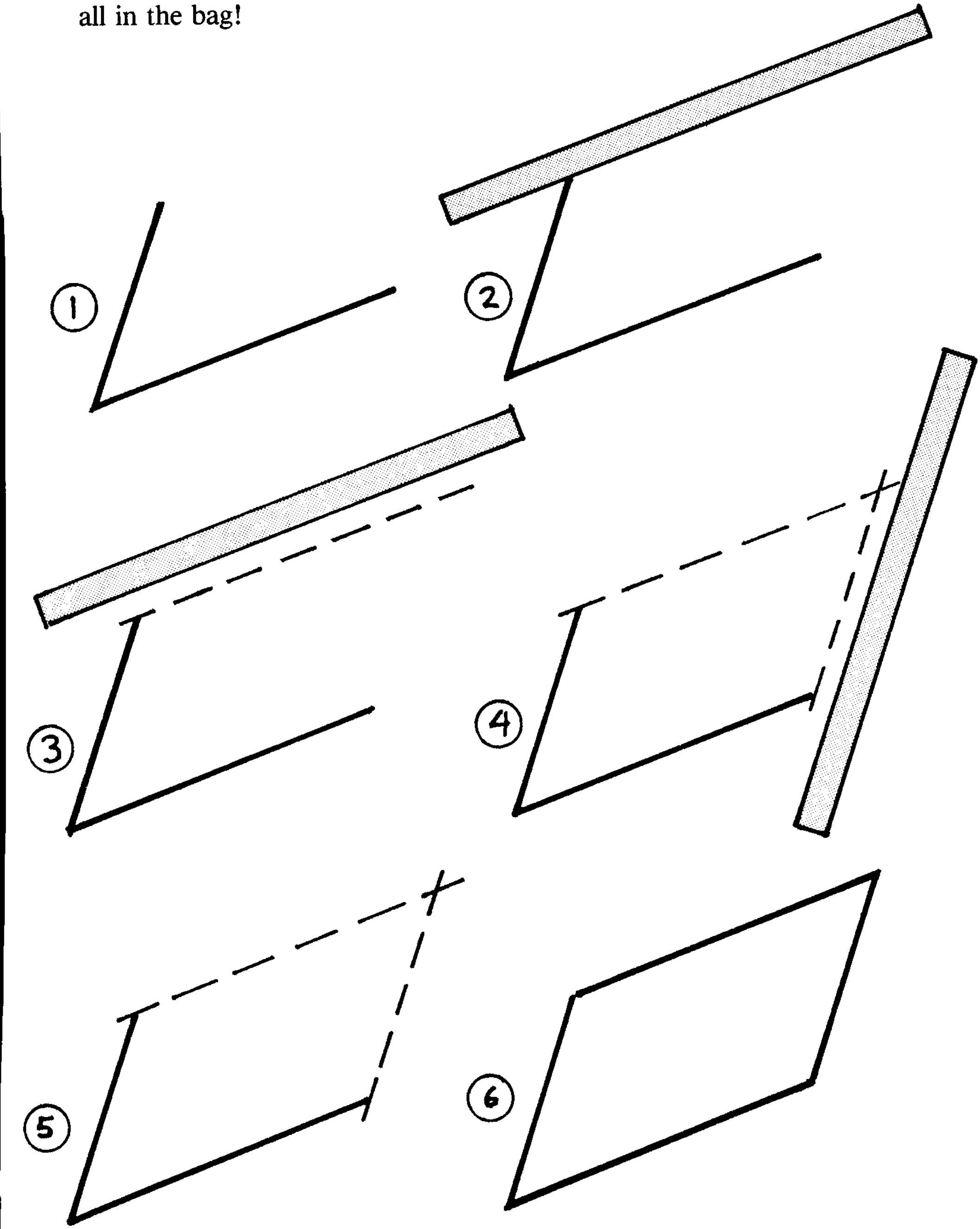
the length of the 10-lb arrow, for if you draw your diagram carefully, it will be to scale.

Now, our strongman did not support the book with the angle we have been discussing. We can see by the sketches that the more horizontal the supporting ropes, the greater is the tension, for our parallelogram must be longer as the base angles are flattened out. In fact, as the ropes approach the horizontal the tension required to produce a vertical 10-lb resultant approaches infinity. It is impossible that the ropes supporting the book could be completely horizontal . . . there must be a kink. So our answer of "more than a million lbs" is rather conservative.



Printed in Whewell's *Elementary Treatise on Mechanics*, 1819.

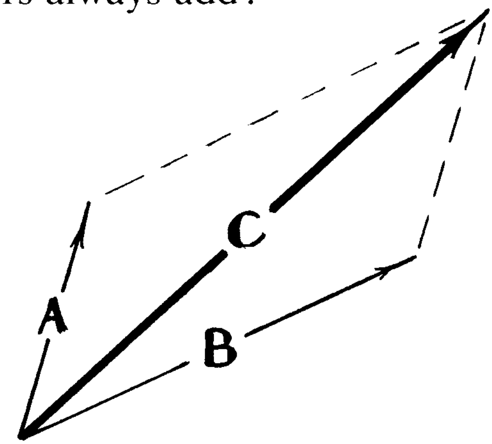
By the way, in case you forgot how to draw a parallelogram, you start with the two sides you have. Then you put down a ruler so it both touches the end of one side and runs parallel to the other side. Next, draw a line. Finally, repeat the same thing for the remaining side . . . and you've got it all in the bag!

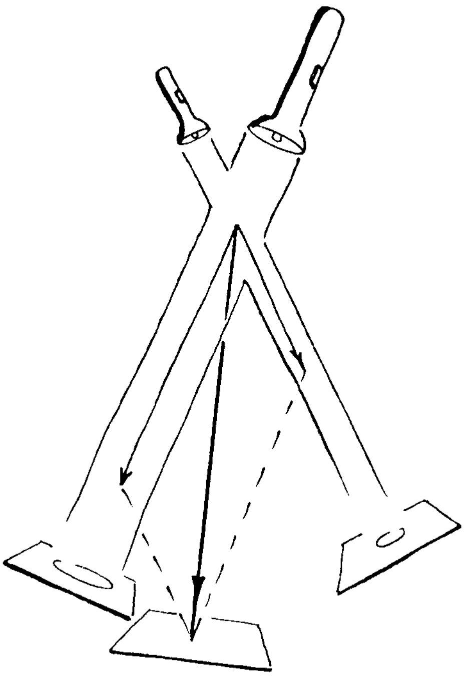


DO VECTORS ALWAYS ADD?

Can two physical things represented by vectors always be represented by one physical thing that is the sum of the two vectors? That is, if vectors A and B each represent the same kind of thing, can the two things acting together always be represented by vector C, which is the diagonal of the parallelogram formed by A and B? In short: do vectors always add?

a) Yes, vectors always add.
b) No, vectors do not always add.





ANSWER: DO VECTORS ALWAYS ADD?

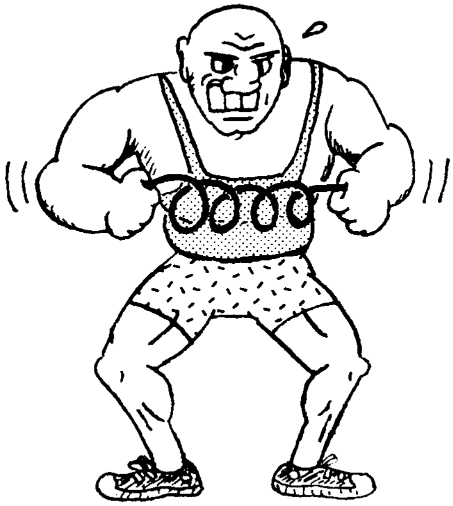
The answer is: b. Most vectors do add. Many physics books presume that anything that can be represented by vectors must add like vectors. For example, some people presume—without proof—that angular momentum vectors add. They do add, but it is not obvious that they do.

And not all vectors add. For example, the power flow in a light beam can be represented by vector. It is called a „Poynting vector." However, if two beams act together, they do not add up to a third beam

FORCE?

The strong man is pulling the spring apart. Is there a force on the spring?

a) Certainly there is.
b) There is no force on the spring.



ANSWER: FORCE

Surprise. The answer is: b. How come? Well, for one thing, a force acts in a definite direction. Which way is the force on the spring acting? To the left or to the right? For another thing, force makes things accelerate. Which way is the spring accelerating? The spring isn't accelerating. It isn't even moving.

Well, if there is no force acting on the spring, what is acting on it? A TENSION. Force and tension are very different, and not appreciating that difference causes quite a bit of confusion. Tensions result from DIFFERENT forces acting on different parts of a body. Tensions can therefore break things. If the same force acts on all parts of a body the body will accelerate in the direction of the force but it will not come apart.

When the same force acts on all parts of a body, the force is called a pure force. Pure forces *can not break things.*

When all the forces acting on a body cancel out or add to zero, as with the spring, the tension is called pure tension. Of course you can think of situations where forces and tensions are mixed.

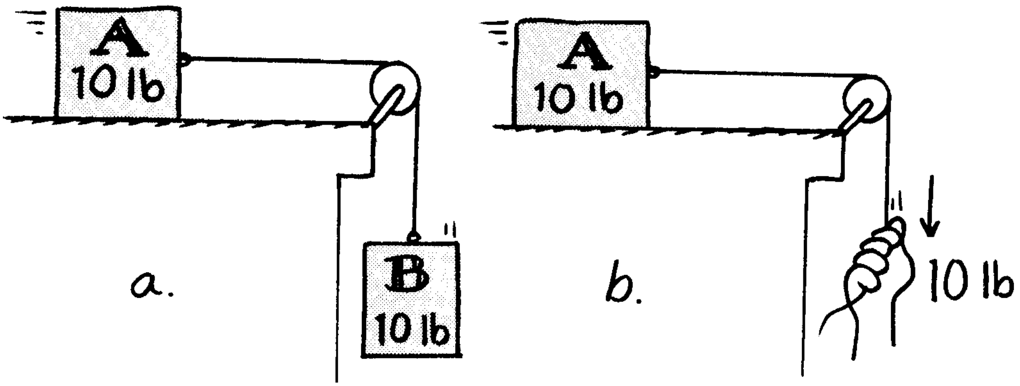
Though force and tension can both be measured in pounds, the difference between them is very deep.* In fact they are intrinsically different kinds of mathematical quantities. A force is a vector and a tension is a tensor.

* Torque and energy also have the same units (foot-pounds) but they are certainly very different physical quantities.

PULL

Think carefully about this one: In both Case *a* and Case *b* shown below a net force of 10 lb results in the acceleration of Block A across the table toward the pulley. Disregard friction altogether.* The acceleration of Block A is

a) greater in Case *a*
b) greater in Case *b*
c) the same in both cases



*But this case *does* involve friction — that between Block A and the surface, the friction of air on the moving blocks, and even friction at the pulley, not to mention the turning of which also tends to impede motion. So how can we simply "disregard friction altogether?" To do so may seem as if we are off in a world of hypothetical, ideal, or imaginary things which don't really exist.

That is partly true. And that is also one of the most powerful keys to understanding the real existing world. In your mind, make the situation simpler than it is by ignoring complications and details. Undress reality. That way the essential part of a situation stands alone and exposed and you can grasp it. Once you grasp the essential part, the essence can be reclothed in its details and complications.

Now how do you know that friction is a complication that can be stripped away? Because in reality you can minimise it as much as you please, if you go to pains to do so. And how do you know what other things can be minimised? Through a working sensitivity about what ultimately can and can't be done in this world. That is the art. Hopefully, this book will help you develop that art.

ANSWER: PULL

The answer is: b. This is because the string tension is not the same in both cases. The tension in the string pulled by hand in Case *b* is 10 lb, and this of course accelerates Block A. But the tension in the string when supplied by the 10-lb falling weight, Case *a*, is less than 10 lb. Why? Because if the tension were a full 10 lb the hanging weight would not accelerate downward at all, but would be in equilibrium. Like if Block A were very very massive compared to Block B and hardly moved, the tension in the string would be close to the full 10 lb, whereas if Block A were very light like a feather, the tension would be very small — the string would be slack and Block B would nearly be in a state of free fall. In our case the mass of Block A is midway between these extremes and is neither more nor less than the mass of Block B. The tension is midway between 10 and 0 lb, and is in fact 5 lb. So Block A accelerates at only half the rate when pulled by the falling weight.

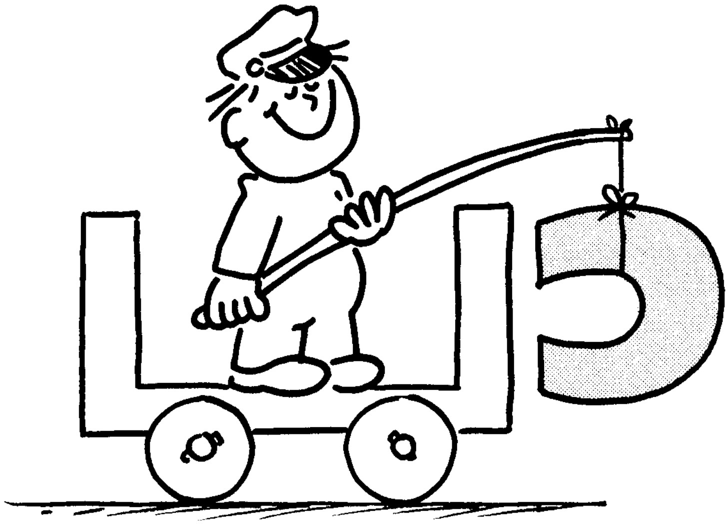
We can see this another way also: Although a force of 10 lb acts in both cases, in Case *a* twice as much mass is being accelerated — the weight of one 10-lb block accelerates the mass of two 10-lb blocks. So we see the acceleration must correspondingly be half the rate as when only the mass of one 10-lb weight is involved. Another thing: Note in Case *b* that a force of 10 lb acts on the mass of a 10-lb body, which means that the acceleration must be 32 ft/s^2 — the same as in free fall (recall FALLING ROCKS).

So Block A accelerates across the table at 32 ft/s^2 when pulled by hand with a force of 10 lb, and at half this rate, 16 ft/s^2, when pulled by a hanging 10-lb weight. The two cases are not equivalent.

MAGNET CAR

Will hanging a magnet in front of an iron car, as shown, make the car go?

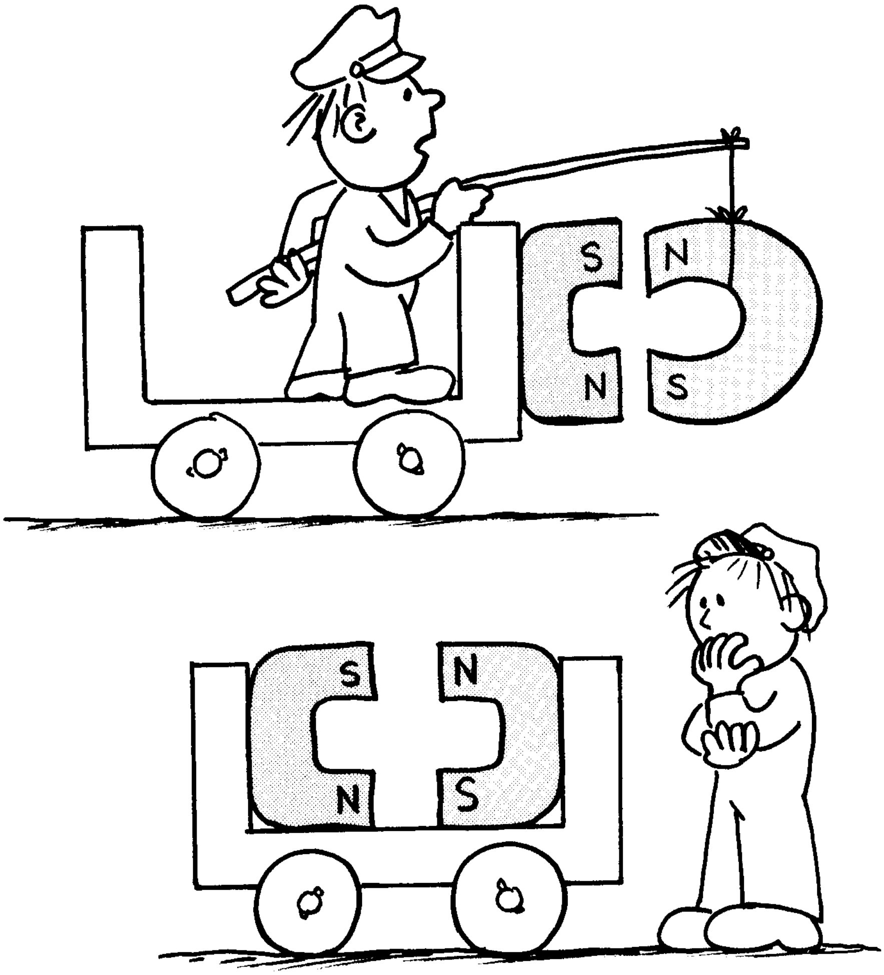
a) Yes, it will go
b) It will move if there is no friction
c) It will not go



ANSWER: MAGNET CAR

The answer is: c. You could just dismiss the thing by saying that no work output will result from zero work input — or perpetual motion is impossible. Or you could invoke Newton's Third Law: the force on the car is equal and opposite to the force on the magnet — so they cancel out. But these formal explanations don't illustrate why it will not work.

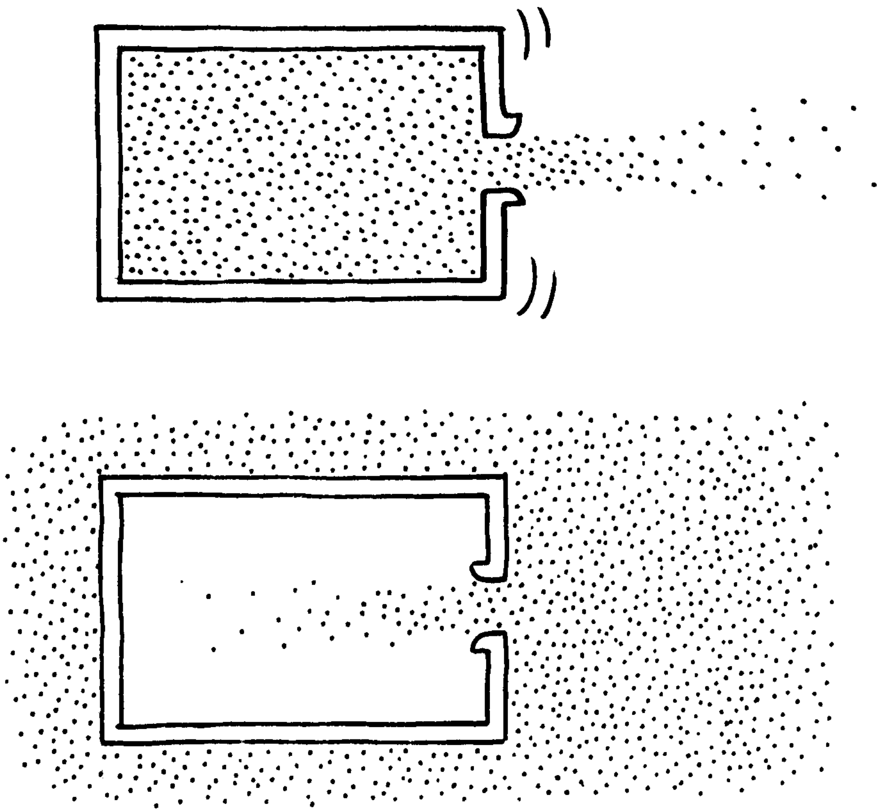
To see intuitively why it will not work, improve the design by putting another magnet in front of the car. Then, to streamline things, put the magnets in the car. Then comes the question: which way will it go?



POOF AND FOOP

This is a stumper. If a can of compressed air is punctured and the escaping air blows to the right, the can will move to the left in a rocket-like fashion. Now consider a vacuum can that is punctured. The air blows in the left as it enters the can. After the vacuum is filled the can will

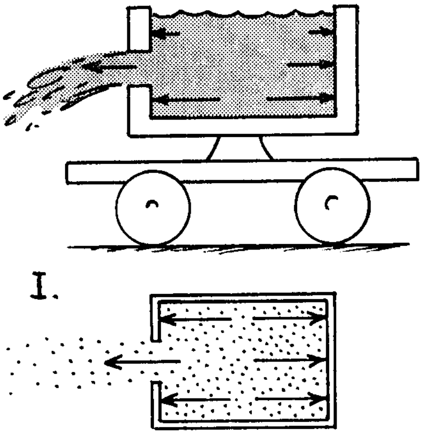
a) be moving to the left
b) be moving to the right
c) not be moving



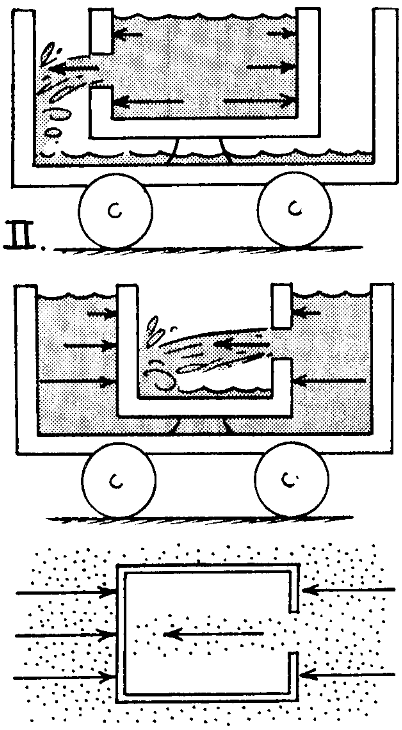
ANSWER: POOF AND FOOP

Are you reading this before you have formulated a reasoned answer in your thinking? If so, do you also exercise your body by watching others do push-ups? If the answers to both these questions is no, and if you have decided on answer c for POOF AND FOOP, you're to be congratulated!

To see why, consider the water-filled cart in Sketch I. We can see that it accelerates to the right because the force of water against its right wall is greater than the force of water against its left wall. The force against the left is less because the "force" that acts on the outlet is not exerted on the cart. Similarly with the can of compressed air. The "force" that acts on the hole is not exerted on the can, and the imbalance accelerates the can to the right.



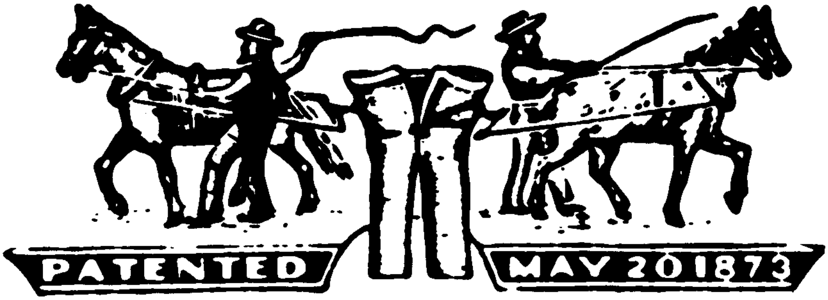
I.



II.

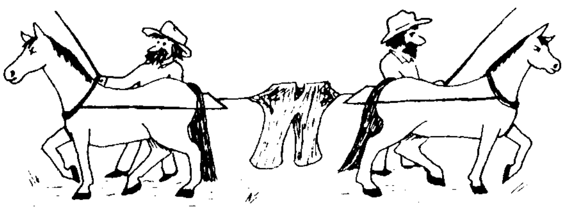
Now consider Sketch II. Do these water-filled carts accelerate? No. Why not? Because the "force" of escaping water *is* exerted on the carts — on the outer wall of the top cart and on the inside wall of the bottom cart. So the water exerts no net force on the carts and no change in motion takes place (except for a momentarily slight oscillation about the center of mass). Likewise with the punctured vacuum can. The force of air that does not act at the hole nevertheless is exerted on another part of the can — on its left inner wall. So like the double-walled cart, the forces are balanced and no rocket propulsion occurs.

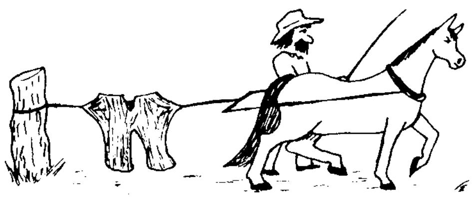
LEVIS



The Levi Strauss trademark shows two horses trying to pull apart a pair of pants. Suppose Levi had only one horse and attached the other side of the pants to a fencepost. Using only one horse would

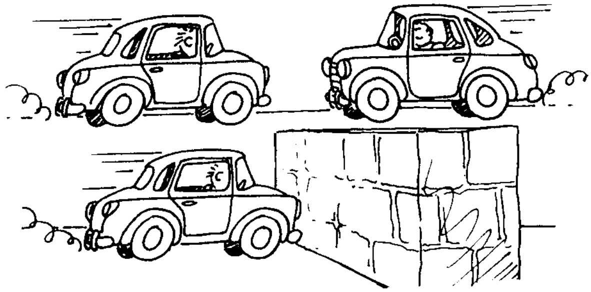
a) cut the tension on the pants by one-half
b) not change the tension on the pants at all
c) double the tension on the pants



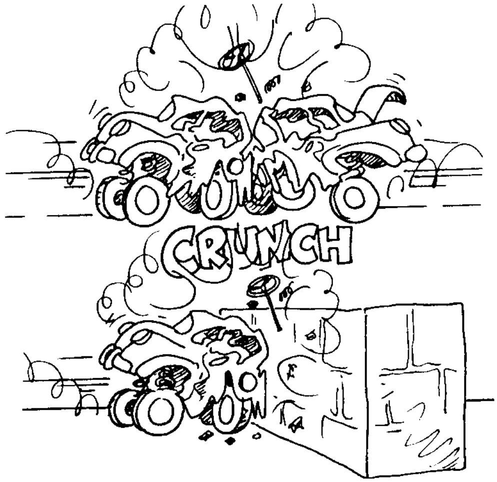


ANSWER: LEVIS

The answer is: b. Suppose one horse can exert one ton of force. Then the other horse must also exert one ton if the tug of war is to be a stand-off. Now if one horse pulls on the post with one ton of force the post must pull back with one ton, for otherwise the horse would pull the pants away. So it doesn't matter if the post pulls or if another horse pulls. Is there any force on the pants? No. Only tension.



The underlying idea developed here can be extended. Suppose two cars of identical mass traveling at 55 mph, but in opposite directions, crash head on into each other. Or suppose one of the cars drives at 55 mph into an immovable stone wall. In which case does the car suffer more damage? There is no difference. The damage is the same in each case.

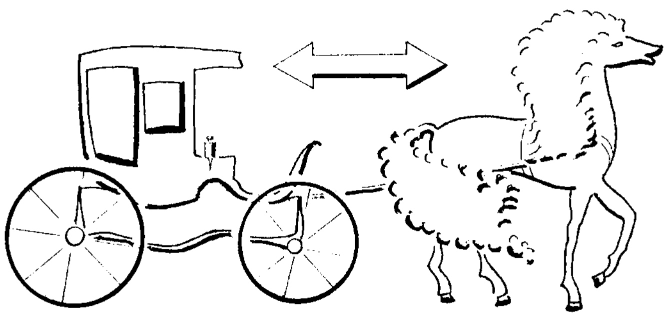


The horse and the car each exert a certain force. That force can be countered by an equivalent horse or car forcing in the opposite direction, or it can be countered by an immovable object. The immovable object in effect acts as a force mirror. It puts out a force that is the mirror image, the reflection, of the force that is applied to it. The wall punches you when you punch it—and just as hard. That is Newton's third law, the reaction law.

HORSE AND BUGGY

This is perhaps the oldest and most famous "brain twister" in classical physics. Which is correct?

a) If action always equals reaction, a horse cannot pull a buggy because the action of the horse on the buggy is exactly cancelled by the reaction of the buggy on the horse. The buggy pulls backward on the horse just as hard as the horse pulls forward on the buggy, so they cannot move.
b) The horse pulls forward slightly harder on the buggy than the buggy pulls backward on the horse, so they move forward.
c) The horse pulls before the buggy has time to react, so they move forward.
d) The horse can pull the buggy forward only if the horse weighs more than the buggy.
e) The force on the buggy is as strong as the force on the horse, but the horse is joined to the earth by its flat hoofs, while the buggy is free to roll on its round wheels.



ANSWER: HORSE AND BUGGY

The answer is: e. True, the force on the horse is as strong as the force on the buggy, but you are interested in motion-acceleration, not force. A thing's acceleration depends on its mass as well as the force on it.

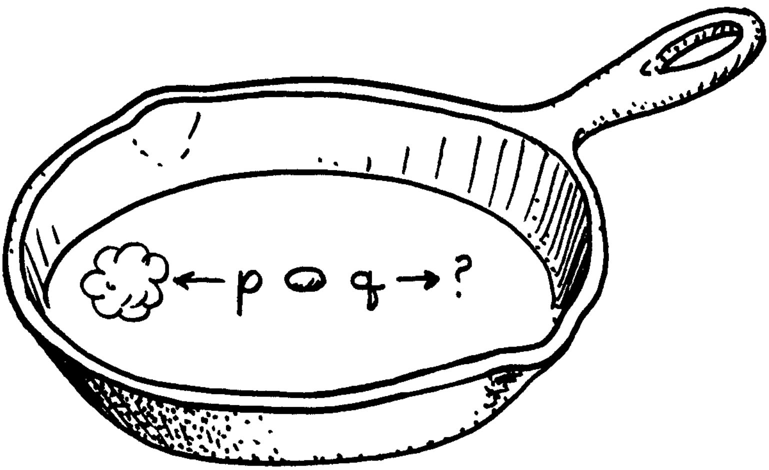
Well, who has the most mass—the horse or the buggy? It doesn't matter, because the horse has joined itself to the earth by its flat hoofs. So in effect one force pulls on the buggy and the equal and opposite reaction pulls on the horse AND EARTH. To pull back the horse also requires pulling back the massive earth, while the buggy, being less massive than the earth, moves much more easily. But as the buggy moves forward, the whole earth moves SLIGHTLY backward.

If the horse pulls the buggy a foot forward, how far backwards does the earth move? Suppose the buggy weighs 1000 pounds. The mass of the earth is 10,000,000,000,000,000,000,000 times greater. So the planet moves a 10,000,000,000,000,000,000,000th part of a foot backwards, which is hard to notice! Incidentally, you can save some ink by writing 10,000,000,000,000,000,000,000 (it has 22 zeros) as 10^{22}.

POPCORN NEUTRINO

In Mom's frying pan a kernel of unpopped popcorn decays into a popped popcorn which shoots off in direction "p." Therefore, during the decay it is probable that

a) a subatomic particle such as a neutrino is emitted in the opposite direction, "q"
b) a neutrino is not involved, but some invisible thing is emitted in direction "q"
c) nothing at all is emitted in direction "q"



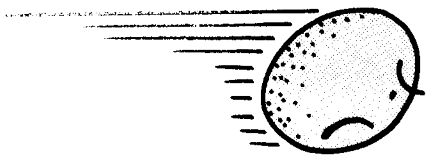
ANSWER: POPCORN NEUTRINO

The answer is: b. If neutrinos came out of popcorn they would have been discovered in the 18th Century. But some invisible thing must shoot from the popcorn. What could have propelled it in direction "p"? What is the invisible thing? Steam. There is moisture in the unpopped kernel and when heated it turns to steam — which explodes the kernel. If the steam shoots off in direction "q," the popped corn recoils in direction "p."

MOMENTUM

Momentum is inertia in motion, and is equal to the product of a body's mass and its velocity. For example, if the speed of a projected cannonball is doubled, then the momentum is doubled. Of if instead the cannonball's mass is doubled, then the momentum is likewise doubled. Suppose, however, that a cannonball's mass is somehow doubled and its velocity is also doubled. Then its momentum is

a) the same
b) doubled
c) quadrupled
d) none of these



ANSWER: MOMENTUM

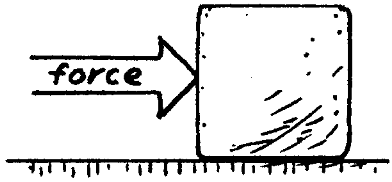
The answer is: c — which follows from the definition of momentum: mass x velocity. Double the mass times double the velocity equals four times the momentum. A body receives momentum by the application of an impulse — which is "FORCE multiplied by the TIME during-which-the-force-acts."

We say that: IMPULSE = change in MOMENTUM.

$Ft = \Delta mv$

GETTING A MOVE ON

Let's develop the impulse and momentum idea further. Consider a block of ice on a friction-free frozen lake. Suppose a continuous force acts on the block. Of course, this causes the block to get a move on, to accelerate. After the force has acted for some time the speed of the block has increased a certain amount. Now if the force and mass of the block are unchanged, but the time the force acts is doubled, then the increase in speed will be



a) unchanged b) doubled c) tripled
d) four-fold e) cut in half

Next, if the force and action time are unchanged, but the mass of the block is doubled, then the speed increase will be

a) unchanged b) doubled c) cut in half
d) four-fold e) cut to one fourth

And now suppose only the force is doubled while the mass and action time are unchanged. Then the increase in speed will be

a) unchanged b) doubled c) cut in half
d) four-fold e) cut to one fourth

Finally, suppose applied force, mass, and action time are all as they were initially, but somehow the force of gravity is doubled — like if the experiment were conducted on another planet. Then the increase in speed will be

a) unchanged b) doubled c) cut in half
d) four-fold e) cut to one fourth

ANSWER: GETTING A MOVE ON

The answer to the first question is: b. The force increases the speed of the block a certain amount each second it acts. If you double the time you simply double the increase in speed.

The answer to the second question is: c. It is harder to move two blocks than one, and a block of double mass is equivalent to two original blocks. It's twice as hard to move the block of double mass, so the speed increase is cut in half. Note that this has nothing to do with gravity. Even if the block were in gravity-free space it would still take a force to change its speed. That's why spacecraft must carry engines for changing their motions even in faraway space. In space the block may have zero weight, but it still has all its mass or inertia (inertia is a synonym for mass) — that is, it still has all its resistance to a change in speed.

The answer to the third question is: b. Force makes the speed change. No force, no speed change. A little force produces a little speed change, a big force produces a big speed change. If you double the force you double the speed change — that is, you double the acceleration.

The answer to the last question is: a. Increasing gravity increases the weight of the block, but not its mass or inertia. It's the inertia of the block that counts. Now if we had to worry about friction, the weight would get into the act because weight controls friction. But the ice sliding on ice that we're concerned with is frictionless.

This whole long story can be abbreviated with one little old equation.* The equation is: Speed change equals force multiplied by time divided by mass

$$\Delta v = \frac{Ft}{m}$$

which is a rearrangement of the Impulse = change in Momentum equation ($Ft = \Delta mv$) we treated briefly in our last question, MOMENTUM.

Another idea: The change in motion needn't be a speed increase. A decrease is also a change. A speed decrease can be regarded like a speed increase if the force is reversed. Moreover, the change in motion can even be sideways if a sideways force acts on the block. Such a change might not even change how fast the block is moving. It might only change its direction of motion!

One last idea: Loosely speaking, we can use the words "speed" and "velocity" interchangeably. But strictly speaking, speed is a measure of how fast without partic-

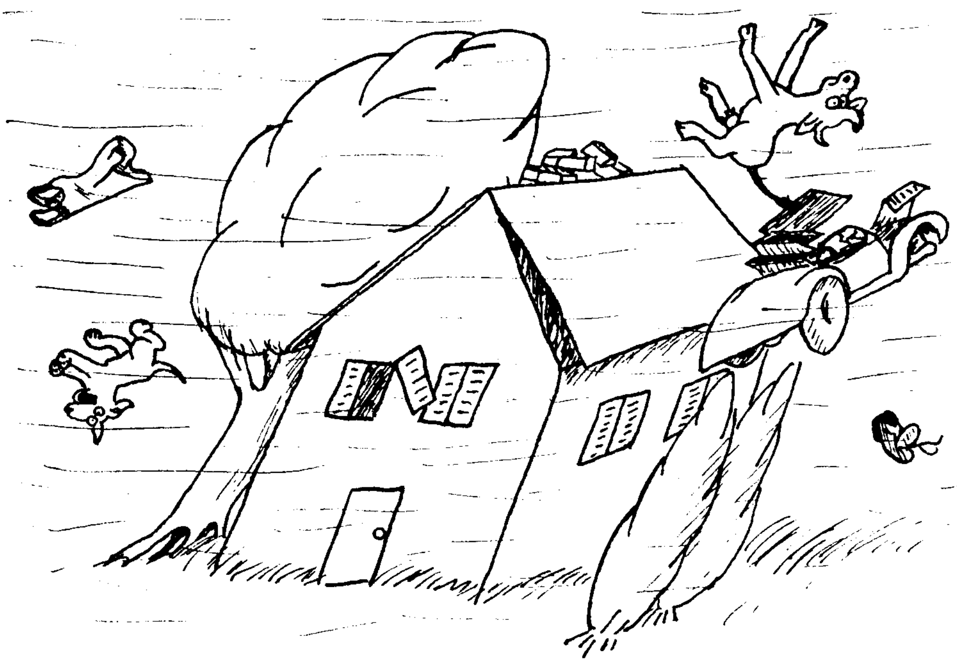
*Equations are useful abbreviations of relationships and are indispensable to the physicist. But often they are misused — when they become substitutes for understanding. Never put your efforts toward memorizing equations until you understand the concepts the symbols represent. Only after a conceptual understanding are the equations truly meaningful.

ular regard for direction; and velocity is the term for speed with particular regard for direction. So velocity may be changing while speed remains constant, like a block at the end of a rope travelling in a circular path (changing direction every instant while its "speedometer" remains constant). So a change in velocity takes account of a change in speed and/or direction, whereas a change in speed is only a change in how fast. Physicists define acceleration to be the inclusive time rate of change of velocity (rather than speed) for this reason.

HURRICANE

The force exerted on a house by a 120-mph hurricane wind is

a) equally . . .
b) twice . . .
c) thrice . . .
d) four times as strong as the force exerted on the same house by a 60-mph gale wind.

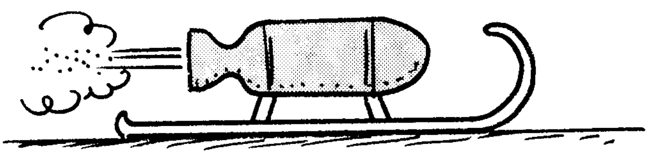


ANSWER: HURRICANE

The answer is: d. If the wind speed is doubled the mass of air hitting the house per second is doubled. But the speed of that mass is also doubled. Double the mass and double the speed means four times as much momentum per second hits the house. The force on the house is proportional to how much momentum hits it per second. So if wind speed doubles force goes up four times. What if wind speed triples? Force goes up nine times.

ROCKET SLED

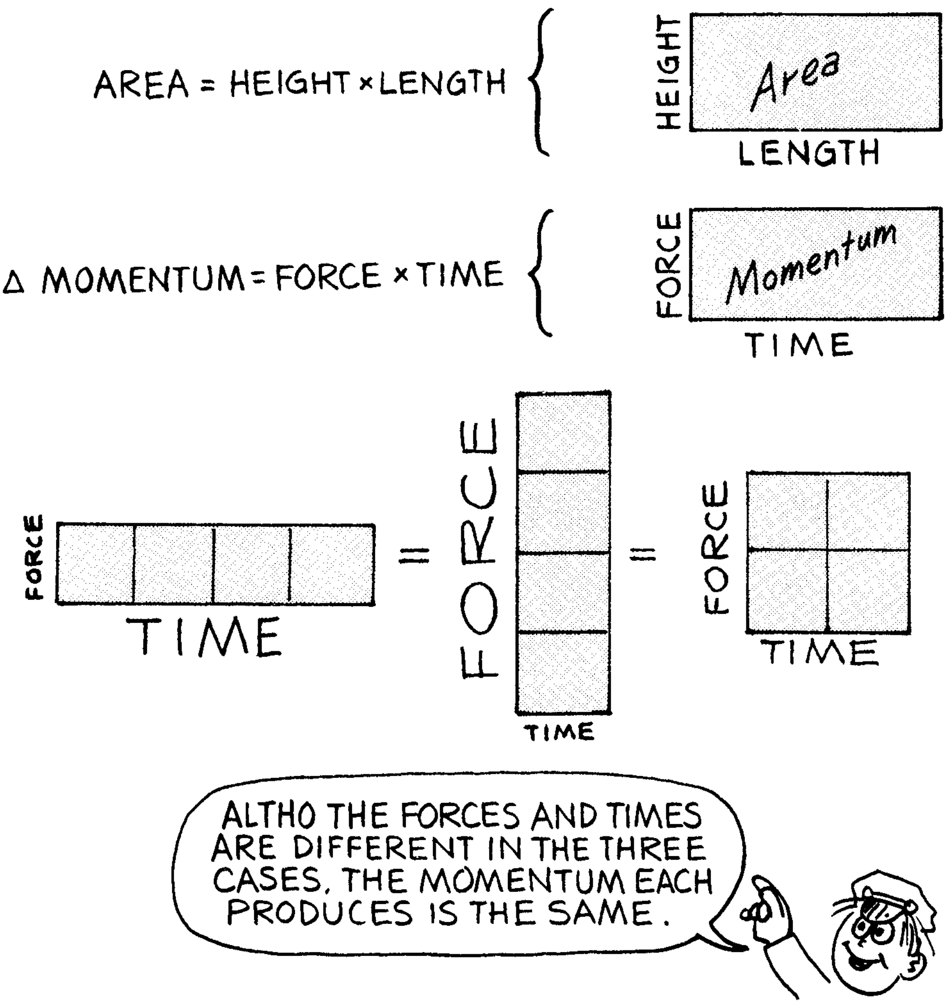
A little sled weighs one pound. It is set in motion over frictionless ice by a toy rocket motor. After the rocket fuel is expended, the sled is coasting over the ice at one foot per second. How much force did the rocket exert on the sled to make it go?



a) One pound
b) 4 pounds
c) 16 pounds
d) 32 pounds
e) There is no way to tell from the information given

ANSWER: ROCKET SLED

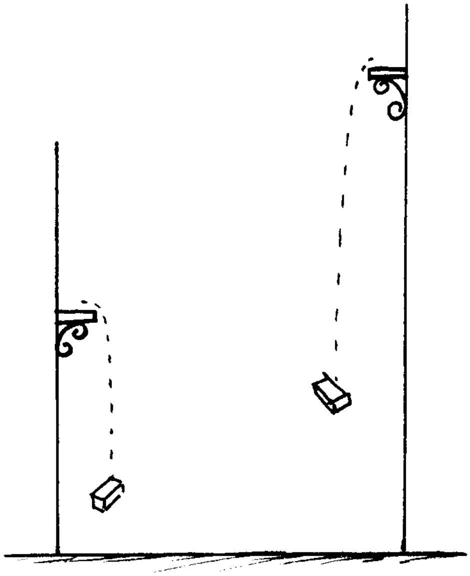
The right answer is: e. That's right, you can't tell! The rocket motor might have provided a small force for a long time or a big force for a short time, but from the information given you can't tell which. This question is very much like asking how long is a rectangle which contains 12 square inches. It might be one long and twelve high or two long and six high or three long and four high. In the case of the sled, its momentum is like the area of the rectangle and the force and time during which the force acts are like the sides of the rectangle which multiply together to make the area.



KINETIC ENERGY

We have seen that a force multiplied by the time-during-which-the-force-acts is equal to the change in momentum of that which the force acts upon: Impulse = Δ Momentum. We now consider another central idea in physics, the work-energy principle. The Work (Force $\times$ Distance-thru-which-the-force-acts) done on a body increases the energy of the body — for example, it can increase its energy of position (gravitational potential energy = weight $\times$ height), which in turn can be converted to energy of motion which is called kinetic energy. Apply this to the following: A brick is lifted to a given height and then dropped to the ground. Next, a second identical brick is lifted twice as high as the first and also dropped to the ground. When the second brick strikes the ground it has

a) half as much kinetic energy as the first
b) as much kinetic energy as the first
c) twice as much kinetic energy as the first
d) four times as much kinetic energy as the first



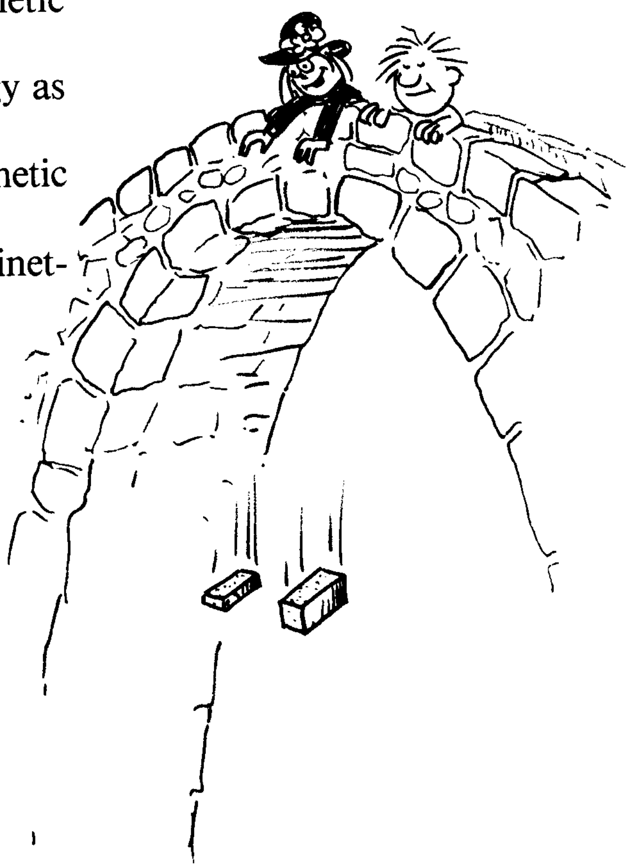
ANSWER: KINETIC ENERGY

The answer is: c. To lift a thing twice as high takes twice as much work and all the work put into lifting the brick turns into kinetic energy as it falls.

MORE KINETIC ENERGY

A brick is lifted to a given height and then dropped to the ground. Next, a second brick, which weighs twice as much as the first, is lifted just as high as the first and then it too is dropped to the ground. When the second brick strikes the ground it has

a) half as much kinetic energy
b) as much kinetic energy as the first
c) twice as much kinetic energy as the first
d) four times as much kinetic energy as the first



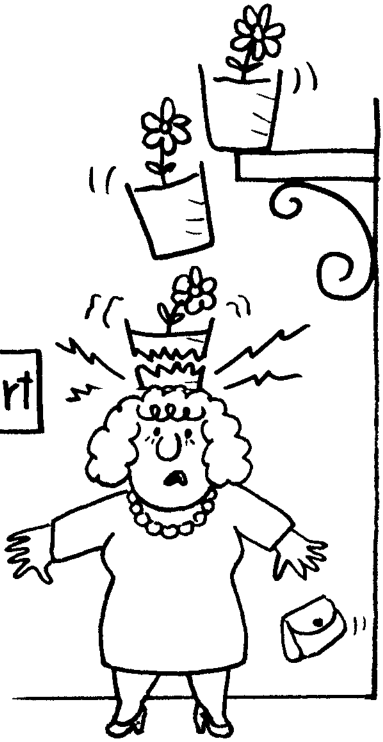
ANSWER: MORE KINETIC ENERGY

The answer is: c. Lifting the brick of double weight is like lifting the first brick twice and so takes twice as much work, which all goes into kinetic energy as it falls.

IN COURT

Preparing his case for trial, a lawyer pondered this question.* A 1-lb flower pot fell one foot from a shelf and struck his client squarely on the head. How much force did the pot exert on his client's head?

a) 1 lb
b) 4 lbs
c) 16 lbs
d) 32 lbs
e) The lawyer's question cannot be answered from the given information



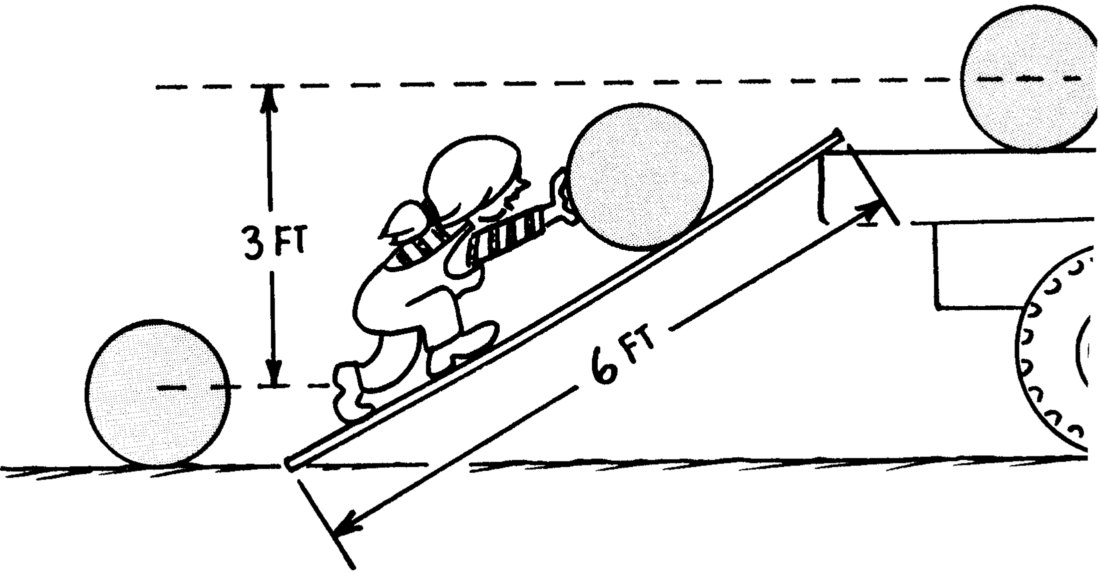
ANSWER: IN COURT

The answer is: e. Why not? This sort of problem should be "duck soup" for a physics major, but no one could answer this without knowing how much "give" was in the skull (and neck and pot and hair or hat, if any). If the pot fell on something with lots of give, like a pillow, there would be very little force. If it fell on something like concrete — smash! If it struck something with no give at all the force would be infinitely large! Suppose there was one inch of give in the client, then all the energy put into the pot during the fall, one foot-pound, must be taken out as it comes to a stop in one inch. Now, an average force of 1 lb acting over one foot does as much work as an average force of 12 lbs acting over one inch. So if there was one inch of give, the average force was 12 lbs. If there was only a half-inch of give, the average force was 24 lbs. (Incidentally, the idea of a hard hat isn't so much that it's hard, but that there is lots of give in the webbing in the hat. Perhaps on another planet in another language they are called "give hats.")

*A question my father asked me — L. Epstein.

STEVEDORE

The stevedore is loading 100-pound drums on a truck by rolling them up a ramp. The truck bed is 3 feet above the street and the ramp is 6 feet long. How much force must she exert on the drums as she goes up the ramp?



a) 200 lb
b) 100 lb
c) 50 lb
d) 10 lb
e) Can't say

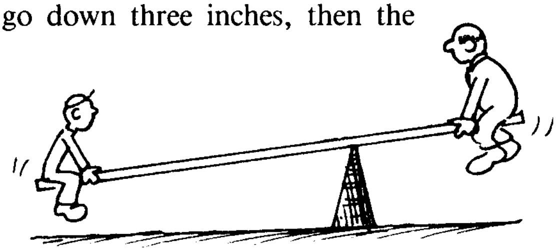
ANSWER: STEVEDORE

The answer is: c. The 100-lb drums end up 3 ft higher than they were, so they end up with 3 ft × 100 lb = 300 ft lb more energy. Now what force exerted over the 6 ft length of the ramp will give 300 ft lb of work? It must be 50 lb of force because 6 ft × 50 lb = 300 ft lb. Three comments:

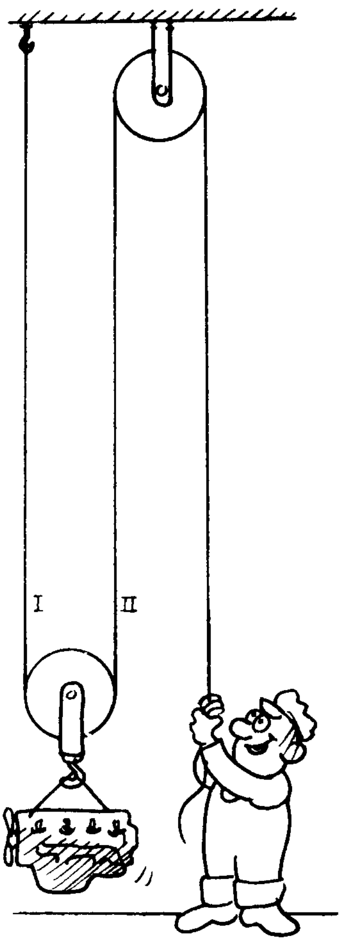
1) Most books solve this type of problem using a different method that involves vectors, as discussed earlier. To see how vectors are used to solve this type problem, look in other books. It's important to see things from different points of view. And it's nice to see that different viewpoints support the same conclusion.

2) If you can't add apples and oranges or feet and pounds, how come you can multiply them?

3) The idea of the inclined plane or ramp is basically the same as the idea that underlies the lever or see-saw and the block and tackle or compound pulley. In each case the force necessary to do a certain amount of work is reduced by increasing the distance over which the force acts. To lift the drum 3 ft requires only half as much force when moved twice as far (6 ft) on the inclined ramp. If lifting the heavy man on the see-saw a distance of one inch requires that the kid go down three inches, then the



weight of the kid need only be one third the weight of the man. Similarly, to lift the engine one meter, the mechanic must pull two meters of rope — one meter from Line I and one meter from Line II — so the mechanic pulls with a force that is only half the weight of the motor.



RIDING UP HILL

Suppose this block is 300 feet long, and quite steep. If I ride my bicycle up the hill along the zigzag path, which is 600 feet long, the average force I must exert is:

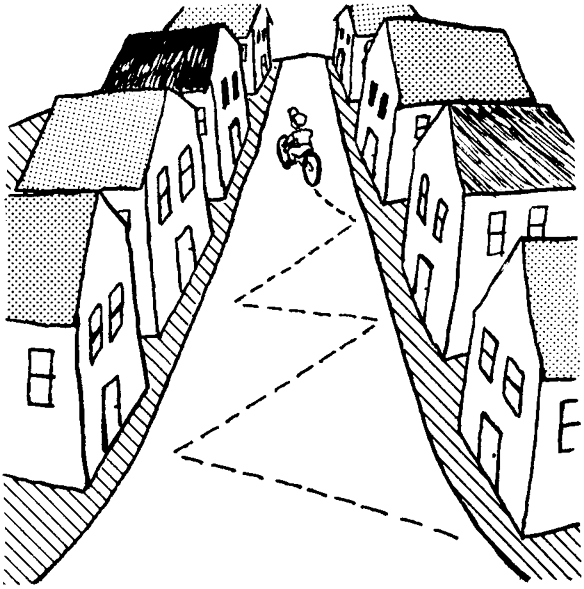
a) 1/4
b) 1/3
c) 1/2
d) equal to

the average force I would exert going straight up.

Again, up the same hill along the zigzag path the energy I must expend is:

a) 1/4
b) 1/3
c) 1/2
d) equal to

the energy I would spend going straight up.



ANSWER: RIDING UP HILL

The answer to the first question is: c; the answer to the second question is: d. All paths to the top require the same energy output. If some paths required more than others, I could go up those that required least and come back down those that required the most and so get back more energy than I put out in the first place—too good to be true.

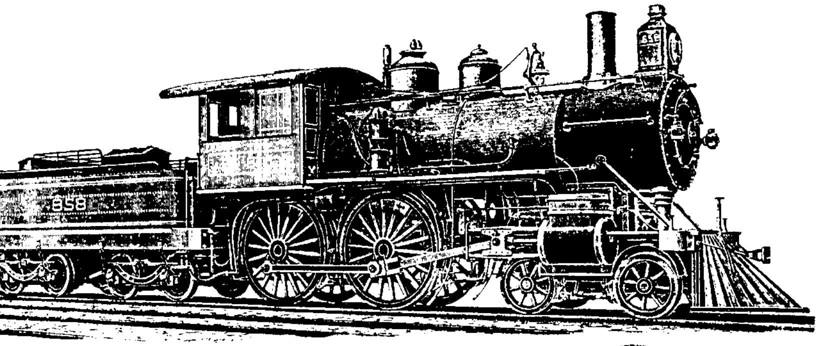
Energy, in this case work, is force multiplied by distance. The energy to get to the top of the hill is the same on both paths but the distance is not the same on both paths. So if the distance gets doubled the force is cut in half.

STEAM LOCOMOTIVE

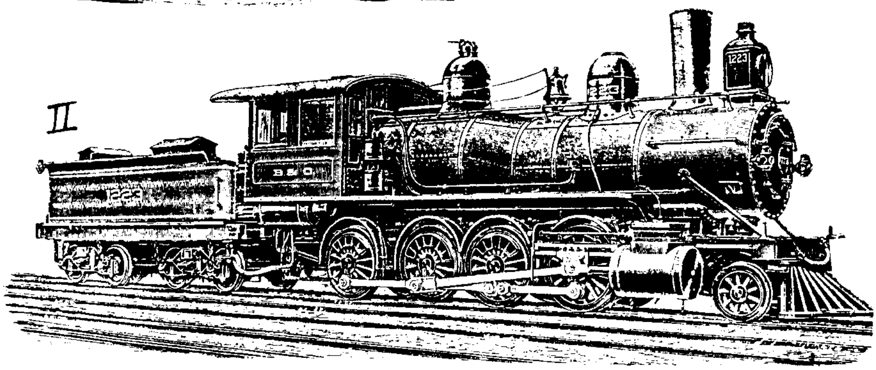
Locomotives for pulling passenger trains are different than locomotives for pulling freight. The passenger locomotive is designed for moving at high speed while the freight locomotive is designed for pulling heavy loads. Consider Locomotives I and II below: Notice the different sizes of the driving wheels and then decide which of the following statements is correct.

a) Locomotive I is for freight trains and II is for passenger trains.
b) Locomotive I is for passenger trains and II is for freight trains.
c) Both are for freight trains.
d) Both are for passenger trains.

I



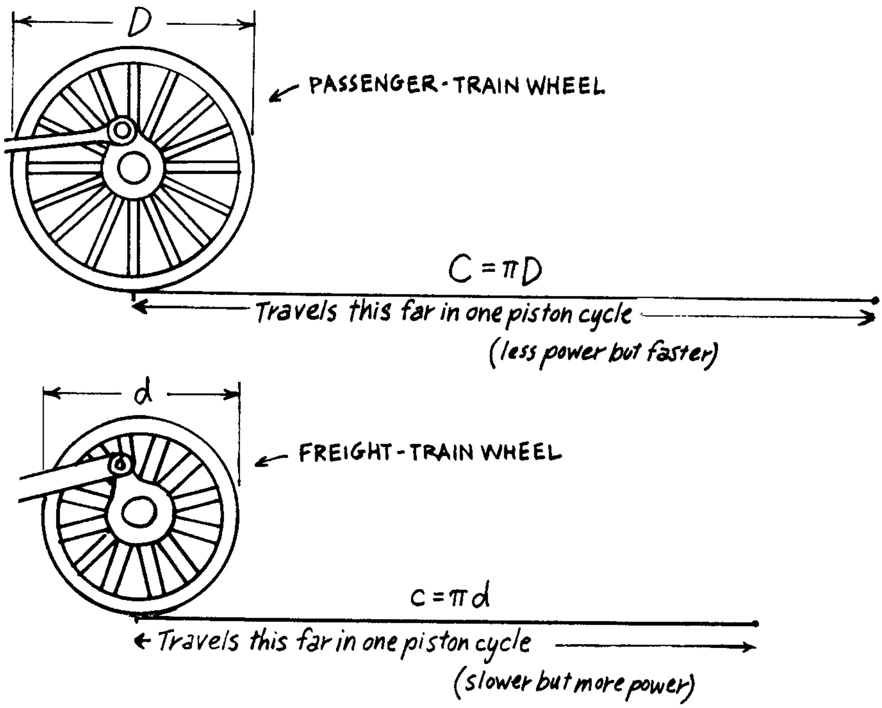
II



ANSWER: STEAM LOCOMOTIVE

The answer is: b. The passenger engine has the larger-diameter driving wheels. Because of the large circumference of the wheels, each piston stroke carries the passenger locomotive a longer distance. So even if both locomotives huff and puff at equal rates, the larger-wheeled passenger locomotive travels faster. The passenger locomotive makes fewer piston strokes and expends less steam per mile of travel than the smaller-wheeled freight locomotive. The freight locomotive therefore packs more steam and energy into each mile it travels. Like a heavy truck traveling in low gear, more energy is required to move the heavy freight train along a mile of track than is required to move the faster but lighter passenger train.

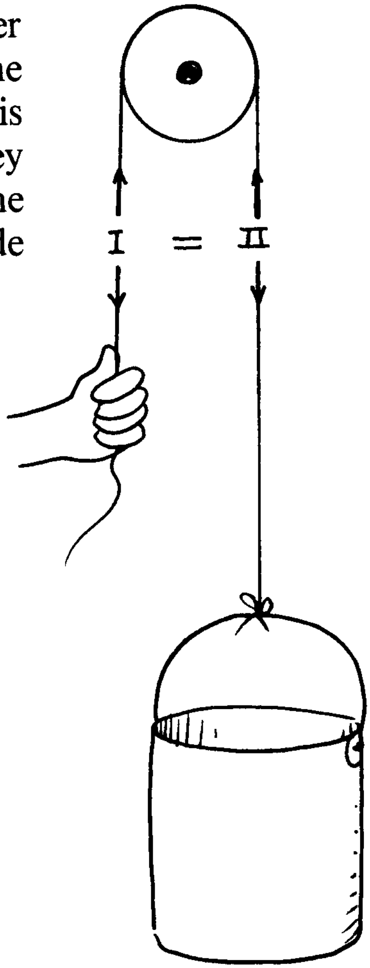
Incidentally, most of the steam locomotives you see these days in movies are freight locomotives, because there were many more of that type made.

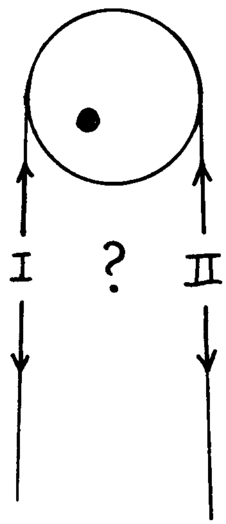


CRAZY PULLEY

The pivot point or axis of an ordinary pulley is at its center, and except for friction effects the tension in the rope that drapes over either side of the pulley is the same. But suppose that the axis were not at the center of the pulley wheel, as shown below. Then the tensions in the rope on each side of the pulley will

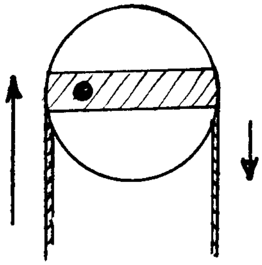
a) still be equal
b) be quite different



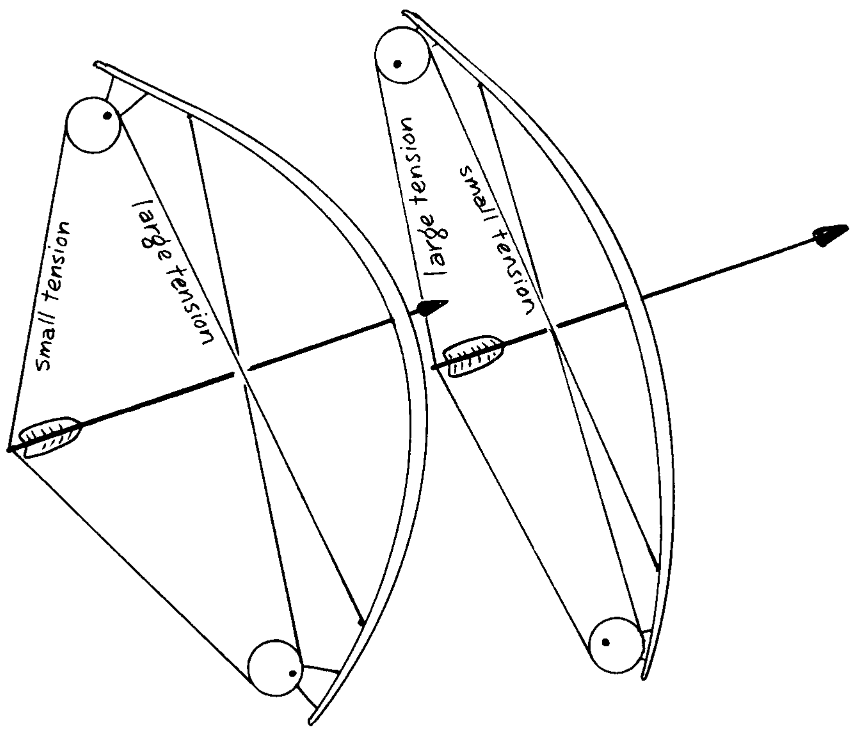


ANSWER: CRAZY PULLEY

The answer is: b. Why? The crazy pulley is a simple lever, disguised.



The crazy pulley is called an *eccentric* pulley. Can you see how the eccentric pulley allows the compound bow to be held in the cocked position with very little tension in the bow string? And can you see that unlike the conventional bow, the tension increases as the arrow is shot?



Incidently, mechanical engineers have a name for this kind of variable leverage mechanism. It is called a *toggle* action. Many electric light switches have toggle action, whence the name *toggle switch.*

RUNNER

A person starts from rest and begins to run. The runner puts a certain amount of momentum into herself and

a) more momentum into the ground
b) less momentum into the ground
c) the same amount of momentum into the ground

A person starts from rest and begins to run. The runner puts a certain amount of kinetic energy into herself and

a) more kinetic energy into the ground
b) less kinetic energy into the ground
c) the same amount of kinetic energy into the ground

ANSWER: RUNNER

The answer to the first question is: c. The answer to the second is: b. The measure of momentum is force multiplied by time. Both the force on the runner and the time during which it is exerted are equal to the force on the ground and the time during which it is exerted; of course the force on the ground is turned around so it pushes backwards. Thus the momentum put into runner and into the earth are equivalent (but opposite).

The measure of energy is force multiplied by distance. The force on runner and earth are equal (though opposite), but the distances they move while the force is exerted ARE NOT EQUAL. The runner might move several feet forward. The massive planet earth does not move a millionth of an inch backwards. So just about zero energy goes into the ground. All the runner's energy goes into the runner.

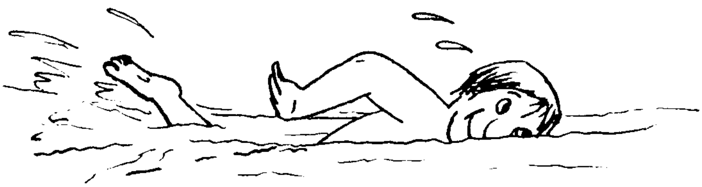
SWIMMER

A person starts from rest and begins to swim. The swimmer puts a certain amount of momentum into himself and

a) more momentum into the water
b) less momentum into the water
c) the same amount of momentum into the water

A person starts from rest and begins to swim. The swimmer puts a certain amount of kinetic energy into himself and

a) more kinetic energy into the water
b) less kinetic energy into the water
c) the same amount of kinetic energy into the water



ANSWER: SWIMMER

The answers are : c and a. The swimmer puts as much momentum into the water as (opposite) momentum into himself for the same reason the runner put equivalent (but opposite) momentum ino the earth and into herself.

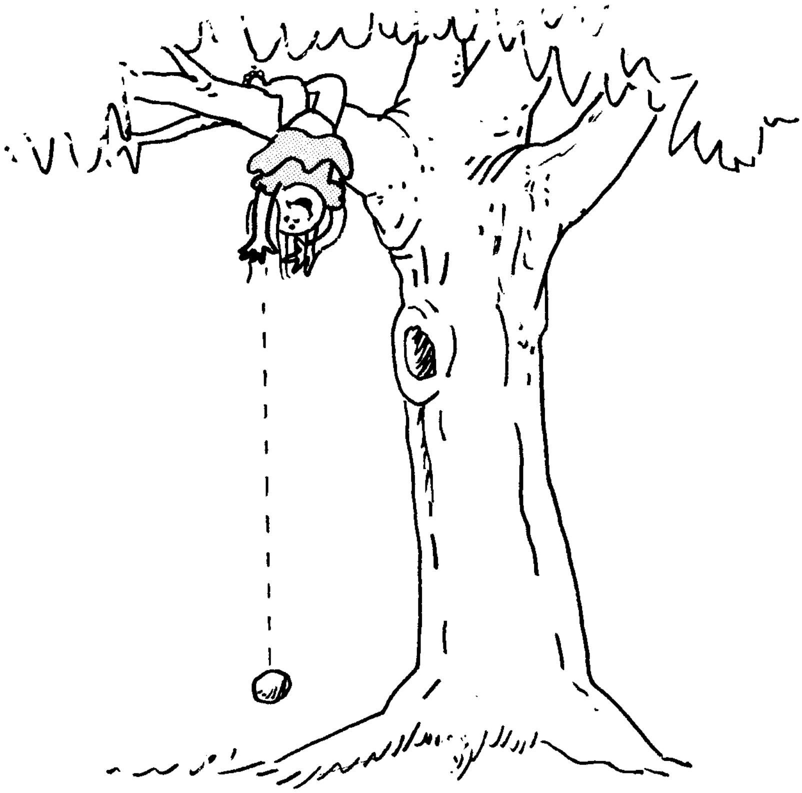
But when you come to energy the story changes. The force on the swimmer and on the water are equal (though opposite). But while the swimmer pushes a handful of water a yard backwards his body moves much less than a yard forward. (This is because the mass of a handful of water is much less than the mass of the swimmer's body.) Since energy is force multiplied by distance, and since each stroke pushes the water farther than the swimmer, more energy goes into the water than into the swimmer.

So the swimmer puts most of his energy into the water while the runner puts almost all of her energy into herself. That's why a poor runner can go faster than an excellent swimmer.

AVERAGE FALLING SPEED

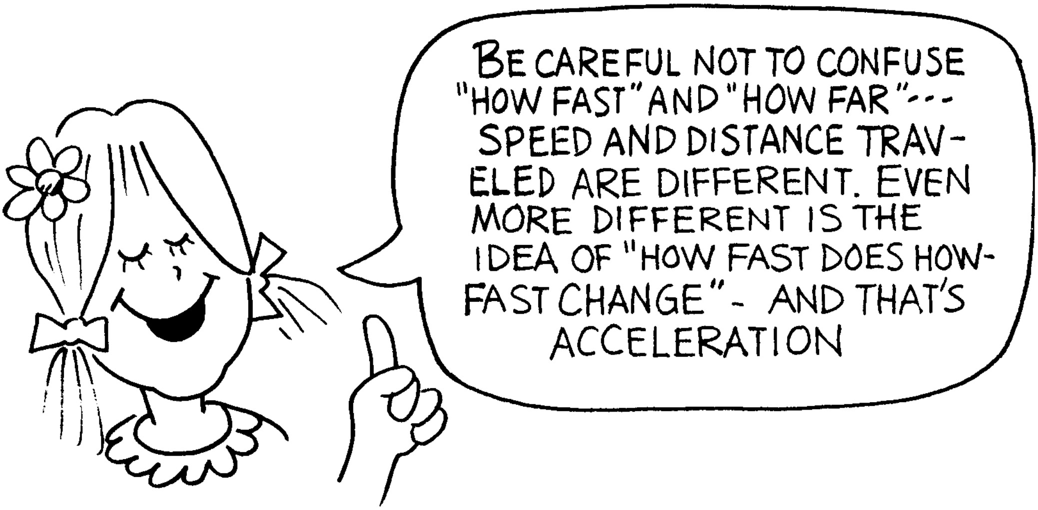
If a rock falls for one second, what is its average speed during that second?

a) Zero ft/s
b) 1 ft/s
c) 4 ft/s
d) 16 ft/s
e) 32 ft/s



ANSWER: AVERAGE FALLING SPEED

The answer is: d. Although the speed of the rock at the end of the one-second interval is 32 ft/s, its beginning speed was zero — it was dropped from a rest position. So the average speed could not be 32 ft/s, anymore than it could be zero. Since the acceleration during the fall was constant, the average speed is simply 16 ft/s, midway between zero and 32 ft/s. We distinguish between instantaneous speed, the speed at a particular instant and the overall or average speed. Incidentally, since the stone has an average speed of 16 ft/s, it must fall a distance of 16 feet during that second.



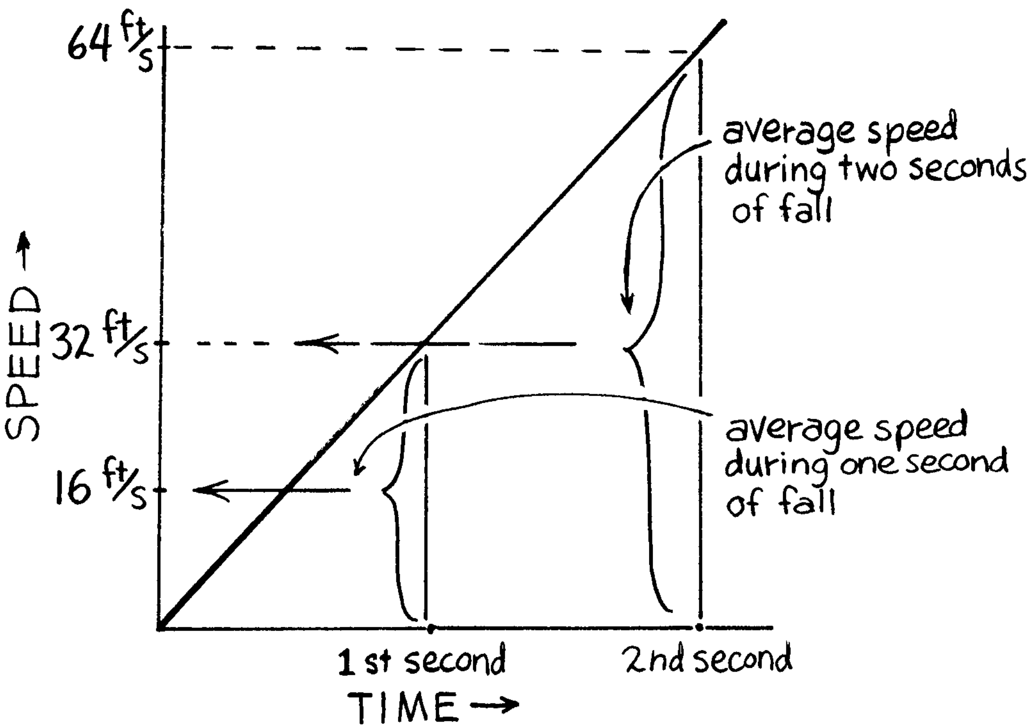
MORE AVERAGE FALLING SPEED

To be sure you understand the previous answer, consider this: If a rock falls for two seconds, what would be its average speed during the two seconds?

a) 1 ft/s
b) 4 ft/s
c) 16 ft/s
d) 32 ft/s
e) 64 ft/s

ANSWER: MORE AVERAGE FALLING SPEED

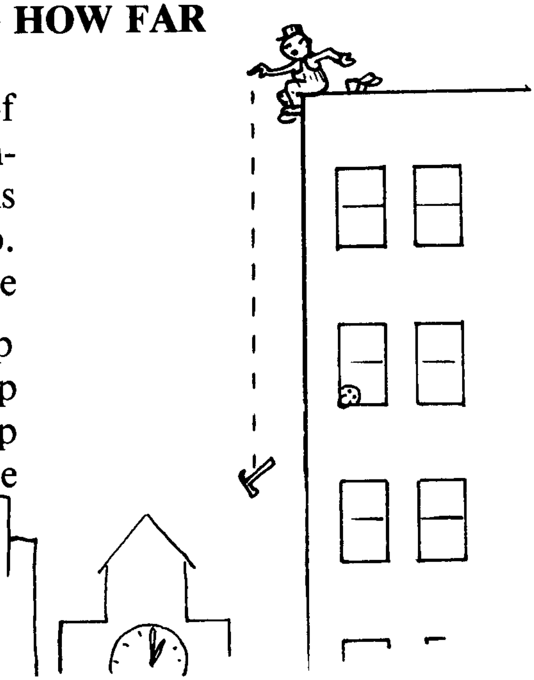
The answer is: d. The speed starts from zero and goes faster and faster at a rate of 32 ft/s every second. After two seconds the speed has increased to sixty-four feet per second ($64 = 2 \times 32$). The average between zero and sixty-four is thirty-two. So 32 ft/s is the average speed. How far did the stone fall during those two seconds? Well, total distance equals average speed multiplied by total time, so total fall distance = 32 ft/s $\times$ 2 seconds = 64 feet.



FALLING HOW FAR

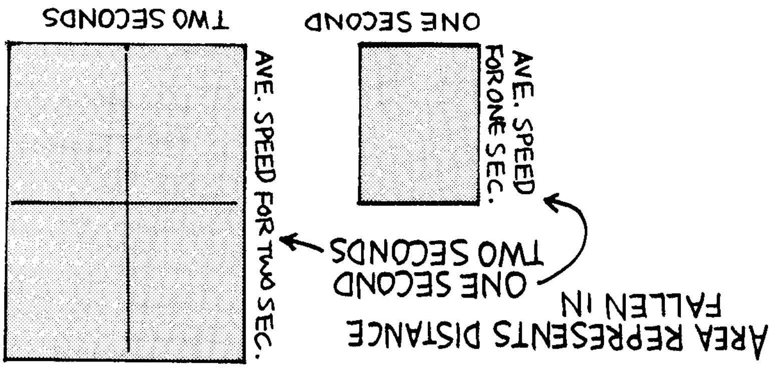
The carpenter at the top of a tall building drops his hammer. In one second it falls one story down from the top. In one more second it will be

a) two stories below the top
b) three stories below the top
c) four stories below the top
d) sixteen stories below the top
e) none of the above



ANSWER: FALLING HOW FAR

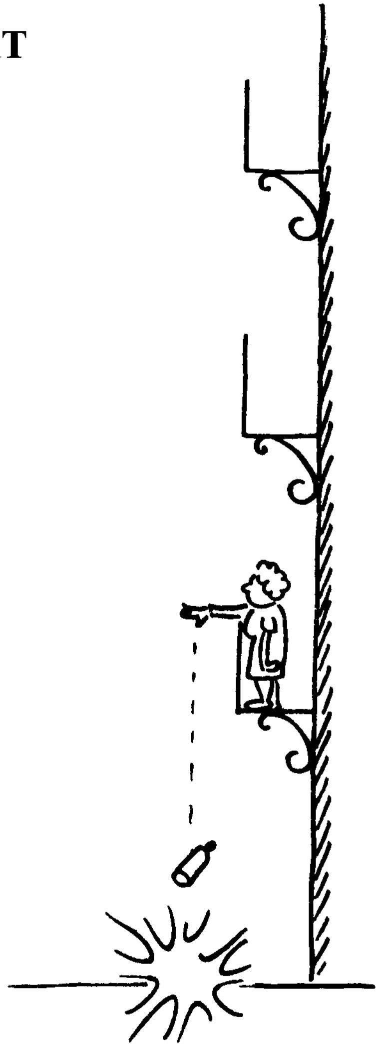
The answer is: c. Some people might think if it went one story in one second it would have gone two stories in two seconds, and that would be true if it fell always at the same speed — but it doesn't. It goes faster and faster as it falls, so its travel during each second is not the same. Its travel increases during each second. After two seconds both the average speed and the time of travel have doubled so the total distance of travel goes up four times. Remember: distance = average speed x time.



SPLAT

A bottle dropped from a balcony strikes the sidewalk with a particular speed. To double the speed of impact you would have to drop the bottle from a balcony

a) twice as high
b) three times as high
c) four times as high
d) five times as high
e) six times as high



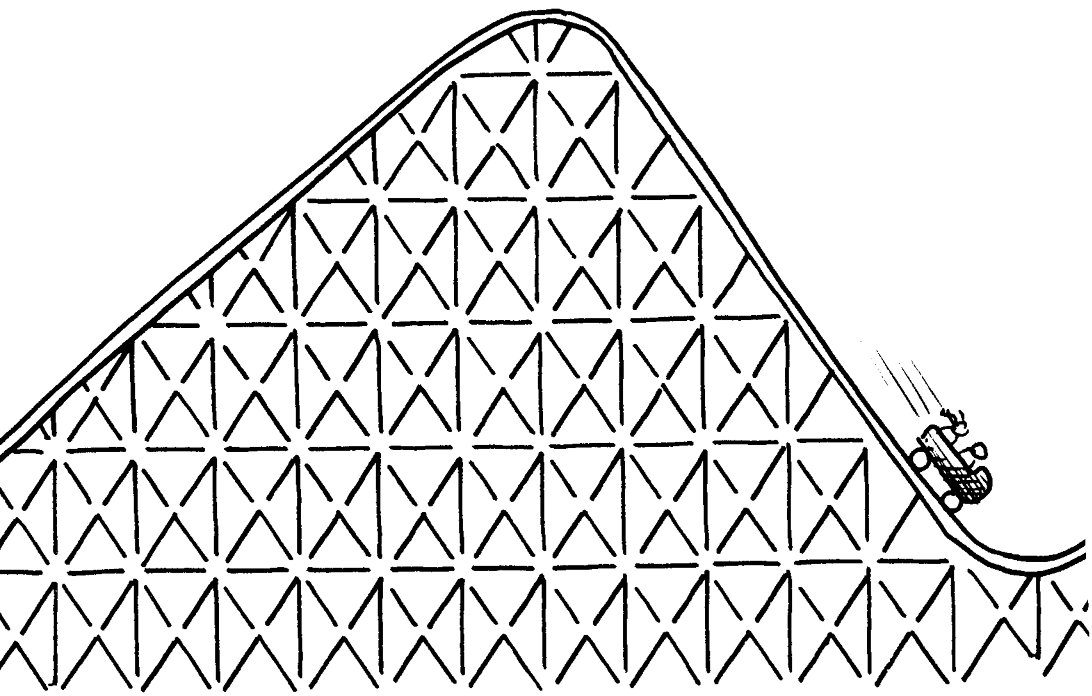
ANSWER: SPLAT

The answer is: c. Simple street sense would seem to suggest a balcony twice as high. But to get double speed it has to fall for double time — and in double time it falls four times as far (recall FALLING HOW FAR). That means you have to lift it four times as far and that means you have to put four times as much energy into it. Now if it goes twice as fast it has twice as much momentum (see MOMENTUM) — but four times as much energy. So doubling the momentum of an object doesn't double the kinetic energy — it increases the energy four times! So we see there is a great difference between kinetic energy and momentum.

SHOOT THE CHUTE

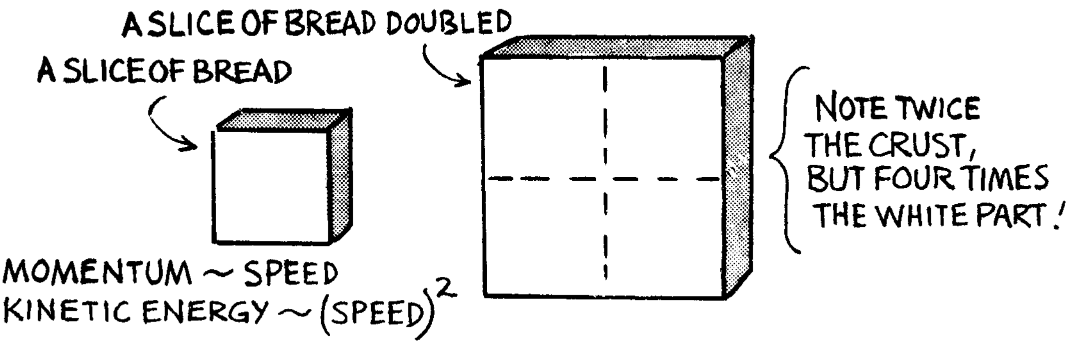
To be sure you understand the preceding question and answer, consider this one: A roller coaster is pulled to the top of a "shoot the chute" and allowed to roll down. For a bigger thrill you might wish the car to be going twice as fast at the bottom of the run. To make your wish come true, the chute should be

a) twice as high
b) three times as high
c) four times as high
d) five times as high
e) six times as high

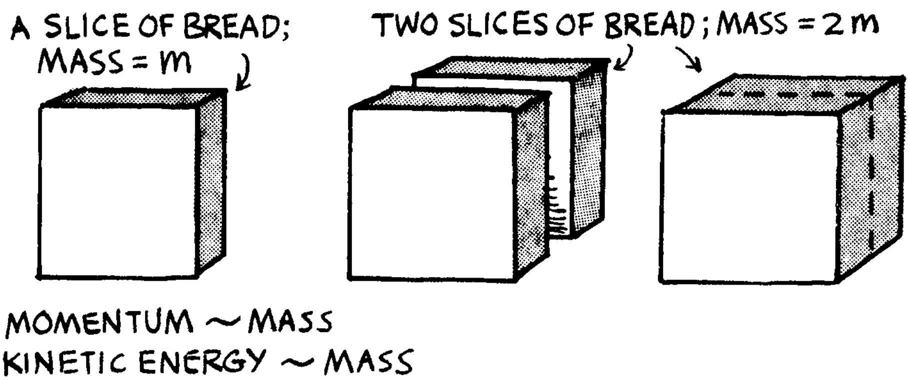


ANSWER: SHOOT THE CHUTE

The answer is: c. This is very much like SPLAT. To double speed you double momentum. To double momentum you increase kinetic energy four times. To increase kinetic energy four times you have to lift four times as far. How can the relationship between kinetic energy and momentum be conceptually visualized? As a slice of bread, the kinetic energy is the white part and the momentum is the crust. If you increase the size of a slice, which corresponds to increasing the speed of an object, you will see the amount of



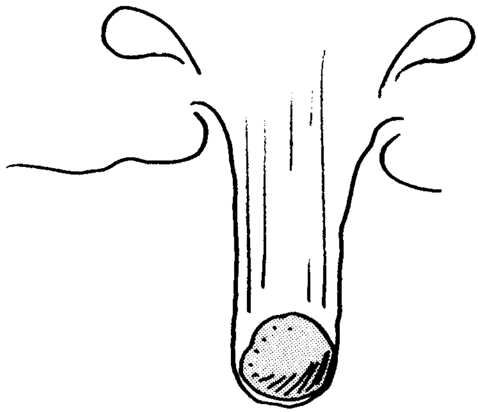
white increases four times while the amount of crust doubles. To conceptualize increasing the mass of the moving object just picture more slices or simply one thicker slice (remember, a two-pound thing is two one-pound things). The slice of bread, crust and white together corresponds to what was once called impedo in the days of Galileo before the distinction between kinetic energy and momentum was clearly recognized.



GUSH

You throw a stone into some nice soft and gushy mud. It penetrates one inch. If you wanted the stone to penetrate four inches, you would have to throw it into the mud

a) twice as fast
b) three times as fast
c) four times as fast
d) eight times as fast
e) sixteen times as fast



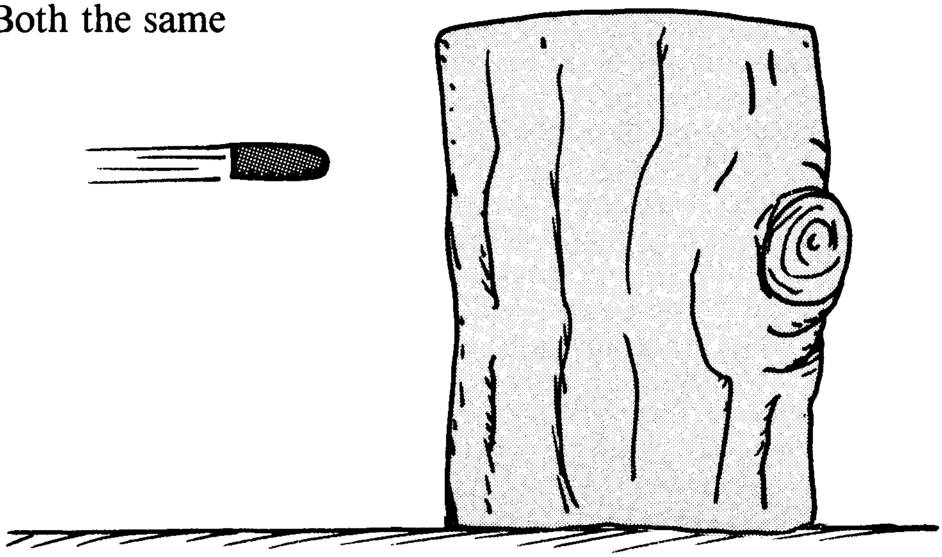
ANSWER: GUSH

The answer is: a. Again, common sense may be misleading. Four times the speed should give four times the penetrating ability, but it isn't so. Why? Push your finger into mud. To no one's surprise a certain force is required. To push four times as far the same force must be exerted over four times the distance. Therefore four times as much energy is required. To increase the kinetic energy in a stone four times, its speed need only be doubled (recall SPLAT). Consider the case of a bullet. If we double the muzzle velocity, while leaving the mass of the bullet unchanged, we will double the bullet's ability to knock things down because its momentum is doubled — but we will increase its ability to penetrate things four times. Kinetic energy and momentum are different from one another.

RUBBER BULLET

A rubber bullet and an aluminum bullet both have the same size, speed, and mass. They are fired at a block of wood. Which is most likely to knock the block over?

a) The rubber bullet
b) The aluminum bullet
c) Both the same



Which is most likely to damage the block?

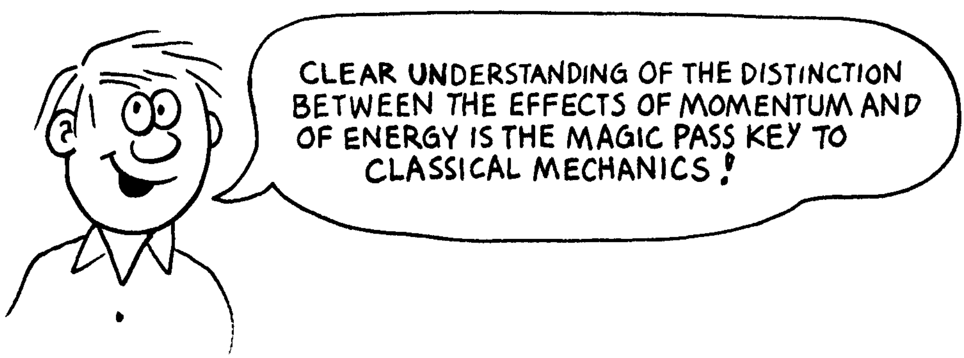
a) The rubber bullet
b) The aluminum bullet
c) Both the same

ANSWER: RUBBER BULLET

The answer to the first question is a, and the second is b. In both cases the equal momenta of the bullets is changed upon impact with the block. But the impulses involved are different because the rubber bullet bounces and the aluminum bullet penetrates. The momentum of the aluminum bullet is completely transferred to the block which supplies the necessary impulse to stop it. But the impulse is greater for the rubber bullet, for the block not only supplies the necessary impulse to stop it, but provides additional impulse to "throw the bullet back out again." Depending on the elasticity of the rebound, this results in up to twice the impulse for the impact of the rubber bullet and therefore up to twice the momentum imparted to the block. So the rubber bullet is very much more likely to knock the block over. If you tell your sharpshooter-type acquaintances that rubber bullets are more effective for knocking things down, they may not believe you — but its true!

Now for the second half of the question. Although the rubber bullet gives the block the most momentum, it does not give it the most energy. If the bullet bounces back with a lot of speed, that means it keeps much of its kinetic energy for itself, whereas the aluminum bullet stops and therefore surrenders all its kinetic energy. The surrendered energy goes into the block. It is most important to note that this added energy the aluminum bullet puts in does not have momentum to go with it! Energy without momentum can't be kinetic energy. It must be some other kind of energy — the energy of heat, deformation and damage.

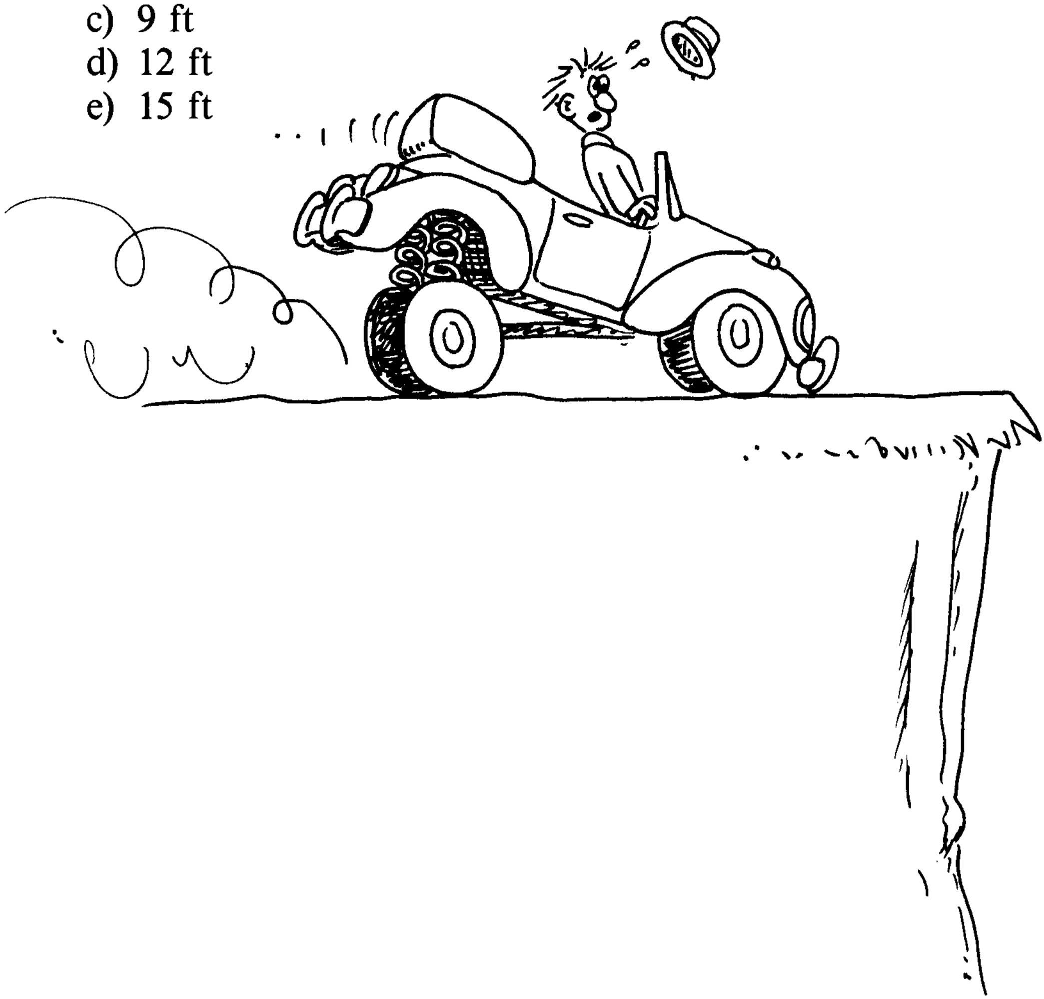
So we see that the rubber bullet puts a lot of momentum but little energy into the block, and the aluminum bullet puts much more energy but less momentum into the block.



STOPPING

A car is going 10 mph. The driver hits the brakes. The car travels 3 feet after the brakes are applied. A while later the same car is going 20 mph. The driver hits the brakes. About how far does the car go after the brakes are applied?

a) 3 ft
b) 6 ft
c) 9 ft
d) 12 ft
e) 15 ft



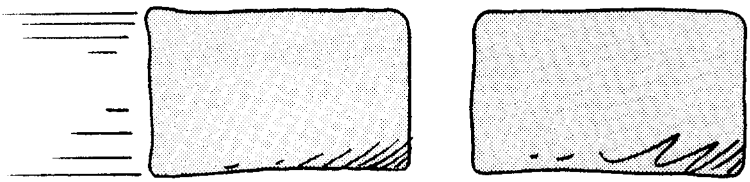
ANSWER: STOPPING

The answer is: d. Stopping a car is like throwing a rock straight up into the air. There is a constant stopping force acting on the car, provided by the brakes. There is a constant stopping force acting on the rock, provided by gravity. To see how a rock acts when it is thrown up into the air just make a movie of one falling down and then run it backwards in your head. In order to double the speed of a falling rock its time of fall must be doubled whereupon its distance of fall automatically increases four times. That means if you throw the rock up with double speed it goes four times as high before stopping.

So also if the car is doing 20 mph. Its stopping distance is four times longer than it was when doing 10 mph. This might be the most practical and important thing you learn from this book. If you double a car's speed, the TIME it takes to stop is doubled, but the DISTANCE it takes to stop goes up FOUR times — and the distance, not the time, determines what you will or will not hit.

SMUSH

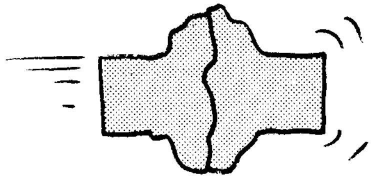
A one-pound lump of clay travelling at one foot per second smashes into another one-pound lump of clay which is not moving. Smush! They stick and become one two-pound lump. What is the speed of the two-pound lump?



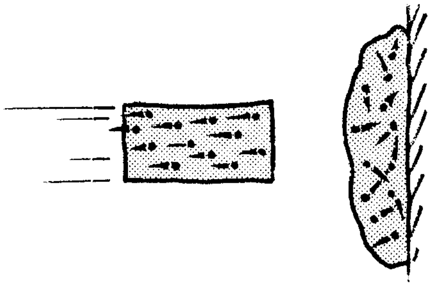
a) Zero ft/s
b) One-quarter of one ft/s
c) One-half of one ft/s
d) One ft/s
e) Two ft/s

ANSWER: SMUSH

The answer is: c. The speed lost by the moving lump goes into the one which was not moving and the exchange goes on until the speeds equalize. Another way to say this is that any momentum lost by the moving lump goes into the one which was not moving. This is because the impulse that increases the speed of the stationary lump is exactly equal and opposite to the impulse slowing the originally moving lump. Since momentum lost by one lump goes into the other, no momentum is lost. So the momentum after collision is the same as before. Momentum is mass multiplied by speed. Before collision all momentum is in the moving lump and none in the stationary lump. The effect of the collision is to double the mass of the originally moving mass without adding or deducting momentum from it. If mass doubles and momentum remains constant the speed must be cut in half. Suppose the one-pound moving lump struck a two-pound stationary lump. Then the effect of the collision is to triple the mass of the originally moving mass without adding or deducting momentum from it. If mass triples and momentum remains constant the speed must be cut to one-third of its original value.

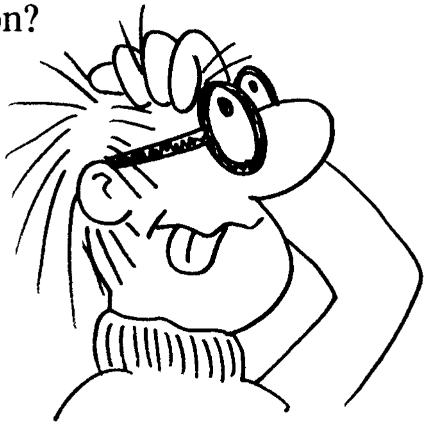


This illustrates a very important law — the Conservation of Momentum. When we make the momentum come out the same at the end as it was in the beginning we are conserving momentum. Why did we not try to think this problem out in terms of conservation of kinetic energy? Because kinetic energy is not conserved. Some of it gets turned to heat when the lumps smash and deform. The deformation takes energy; in a car accident the energy is required to "bend the tin." If a lump of clay hits a stone wall all the kinetic energy gets turned to heat. But if a perfectly elastic ball hits a stone wall it bounces off without turning any of its kinetic energy into heat and therefore doesn't lose any of its kinetic energy. There is one more thing worth saying here. In a way, heat is really hidden kinetic energy. When all the molecules are moving in the same direction it is called ordinary kinetic energy or mechanical kinetic energy. When all the molecules are bouncing about in different directions the clay as a whole does not move, the kinetic energy is mixed up and hidden, and it is called thermal kinetic energy or heat.



SMUSH AGAIN

A one-pound lump of clay travelling at one foot per second smashes into another one-pound lump of clay which is not moving. Smush again! They stick and become one two-pound lump of clay. What proportion of the kinetic energy in the originally moving lump was turned into heat during the collision?



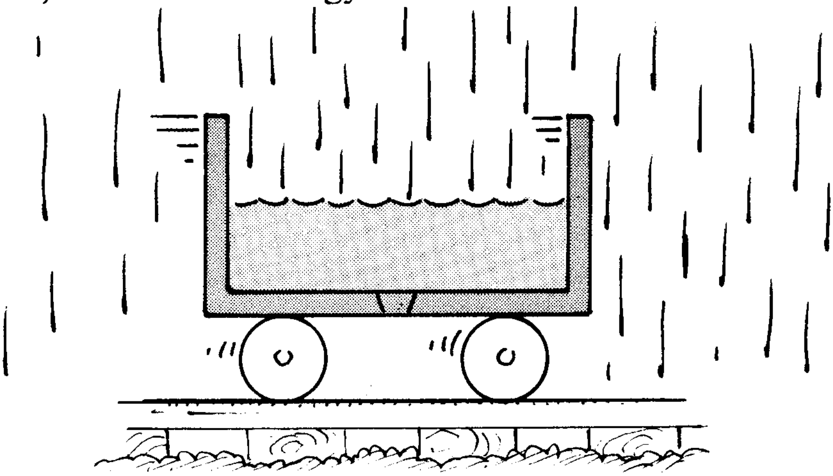
a) Zero%
b) 25%
c) 50%
d) 75%
e) 100%, that is, all the kinetic energy was turned into heat

ANSWER: SMUSH AGAIN

The answer is: c. Recall from SMUSH that the speed of the lumps when stuck together is half the speed of the single lump before smushing. Now think of the two-pound lumps as a pair of one-pound lumps. Since these lumps are moving only half as fast as the lump that did the hitting, their kinetic energies must each be one-quarter that of the single lump before smushing (recall SPLAT). Since there are two lumps in the pair, there is $\frac{1}{4} + \frac{1}{4} = \frac{1}{2}$ as much energy as in the original single lump. So half (50%) of the kinetic energy in the originally moving lump ends up as kinetic energy in the two-pound lump. The lost half was turned into heat. What if they made a noise — like smush — when they came together? Would not that noise take some of the lost kinetic energy, so not all of it would turn into heat? But what becomes of noise? What becomes of all sound, talk included? What is a synonym for talk? Hot air. A noise turns into heat and does so very quickly. How quickly? In the time it takes an echo to die.

ROLLING IN THE RAIN

Suppose an open railroad car is rolling without friction in a vertically-falling downpour and an appreciable amount of rain falls into the car and accumulates there. Consider the effect of the accumulating rain on the speed, momentum, and kinetic energy of the car.



The *speed* of the car will

a) increase
b) decrease
c) not change

The *momentum* of the car will

a) increase
b) decrease
c) not change

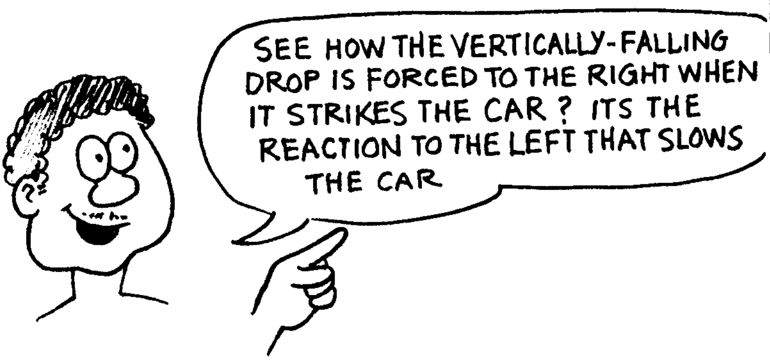
And the *kinetic energy* of the car will

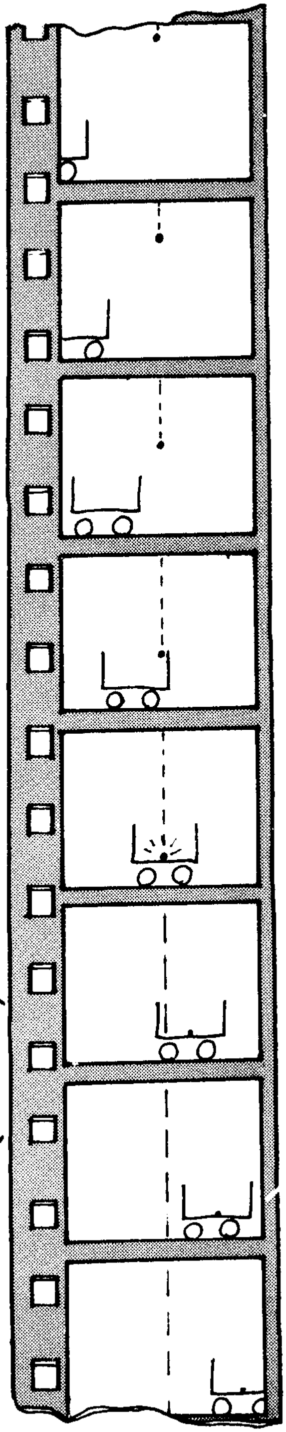
a) increase
b) decrease
c) not change

ANSWER: ROLLING IN THE RAIN

The answer to the first question is b; the second c; and the third, b. The rolling car has momentum only in the horizontal direction. The rain falls straight downward and has no horizontal momentum to add to the car. So the momentum of the car doesn't change. The mass of the car, however, does change — it's increased by the mass of accumulated rain. A mass increase while momentum is constant results in a decrease in velocity. So the car slows down as rain accumulates. This situation is almost a repeat of SMUSH AGAIN. Speed and kinetic energy are cut while momentum is uneffected. What happens to the lost kinetic energy? It goes into heat — the water in the car is a bit warmer than the rain.

We have reasoned so far with only the conservation rules for momentum and energy. Answers to many questions are provided by these powerful rules that completely bypass often very messy forces. But let's think about force anyway to better understand our conclusions. The falling rain that hits the car ends up with the horizontal velocity of the car. So a force had to act on it, whether by interaction with the wall, floor, or surface of accumulated water. Whatever force acts on the raindrops to give them a horizontal velocity also acts on the car. It is this reaction force that slows the car.





ROLLING DRAIN

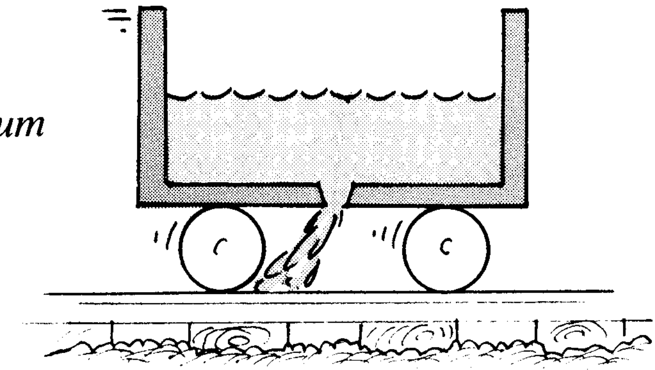
The rain has stopped. A drain plug is opened in the bottom of the rolling car allowing the accumulated water to run out. Consider the effects of the draining water on the speed, momentum, and kinetic energy of the rolling car.

The *speed* of the car will

a) increase
b) decrease
c) not change

The *momentum* of the car will

a) increase
b) decrease
c) not change



And the *kinetic energy* of the car will

a) increase
b) decrease
c) not change

ANSWER: ROLLING DRAIN

The answer to the first question is c; the second b; and the third, b. If you simply let go of something you are holding, it does not exert any force on you and you do not exert any force on it. As the water is released from the car it exerts no force on the car so the speed of the car is not changed. The water just drops away with the same horizontal velocity it had while in the car — like some clod dropping a beer can out of the window of a moving car. Of course the departing water takes its momentum and kinetic energy with it when it goes. So the car is left with less momentum and less kinetic energy.

HOW MUCH MORE ENERGY

This one will stump most readers. The chemical potential energy in a certain amount of gasoline is converted to kinetic energy in a car that increases its speed from 0 mph to 32 mph. To pass another car the driver accelerates to 64 mph. Compared to the energy required to go from 0 to 32 mph, the energy required to go from 32 mph to 64 mph is

a) half as much
b) as much
c) twice as much
d) three times as much
e) four times as much

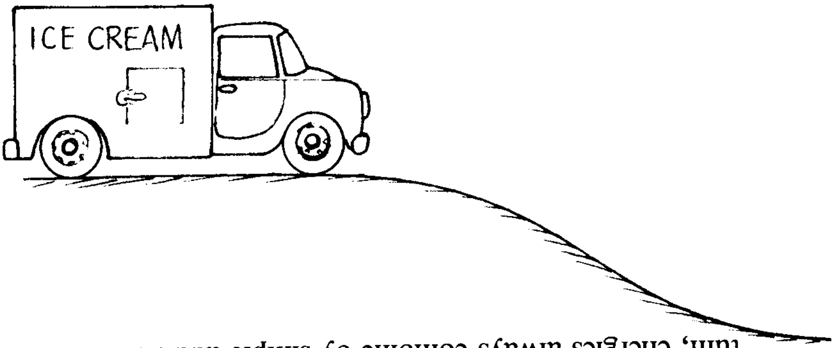
ANSWER: HOW MUCH MORE ENERGY

The answer is: d. The speed increase from 0 to 32 mph was 32 mph and that from 32 mph to 64 mph was also 32 mph so you might think the energy increase was the same in both cases, but if so you are in for a new view. Pretend 0 mph, 32 mph, and 64 mph are 0 ft/s, 32 ft/s, and 64 ft/s, and recall FALLING HOW FAR. The object going 64 ft/s must have fallen for twice as much time and four times as much distance as the one going 32 ft/s. So the faster one has four times as much kinetic energy as the slow one. Let us suppose that 32 mph or 32 ft/s is equivalent to one "drop" of kinetic energy. Then 64 mph or 64 ft/s equals four "drops" of kinetic energy (say big drops for mph, and little drops for ft/s). So to get from 32 to 64 you have to add three more "drops."

SPEED AIN'T ENERGY

A truck initially at rest at the top of a hill is allowed to roll down. At the bottom its speed is 4 mph. Next, the truck is again rolled down the hill, but this time it does not start from rest. It has an initial speed of 3 mph on top, even before it starts going down the hill. How fast is it going when it gets to the bottom?

a) 3 mph
b) 4 mph
c) 5 mph
d) 6 mph
e) 7 mph



ANSWER: SPEED AIN'T ENERGY

The answer is *not* e — if you chose this answer, 7 mph, go back and *think* some more. You might review HOW MUCH MORE ENERGY!

Going down the hill adds a certain amount of kinetic energy, but *NOT a certain amount of speed.* If it is just added speed, the answer would be 3 + 4 = 7, but this is *wrong.*

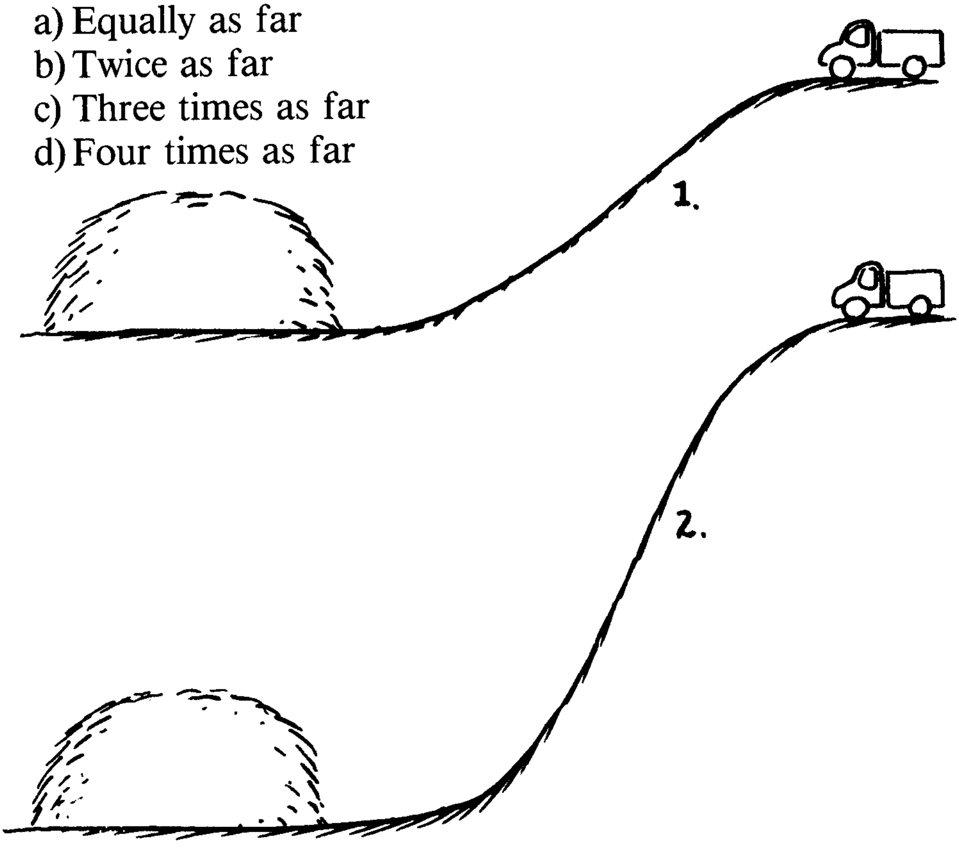
But why don't the speeds add? Because to pick up 4 mph on the hill the truck must spend a certain amount of time on the hill. When it starts off at 3 mph it spends less time on the hill and so picks up less speed going down. We can, however, find something that *does* add — and that's energy. We know doubling speed increases energy four times, and tripling speed increases the energy nine times and so on. Kinetic energy is proportional to the square of the speed. So if the initial speed 3 has 9 units of energy, speed 4 (which rolling down the hill provides) has 16. So the total energy is 9 + 16 = 25 energy units. Now 25 energy units corresponds to what speed? Speed 5 — so the answer is: c.

Note that the kind of speed or energy units is not really important here. If the speed were meters per second rather than miles per hour the answer would simply have been 5 m/s rather than 5 mph. The important thing is that energies are proportional to the speeds squared, and unlike momentum, energies always combine by simple addition.

PENETRATION

A truck initially at rest rolls down Hill 1 into a very big haystack. Another identical truck also rolls from rest down Hill 2, twice as high, into an identical haystack. Compared to the truck on Hill 1, how much farther does the truck on Hill 2 penetrate into the stack?

a) Equally as far
b) Twice as far
c) Three times as far
d) Four times as far

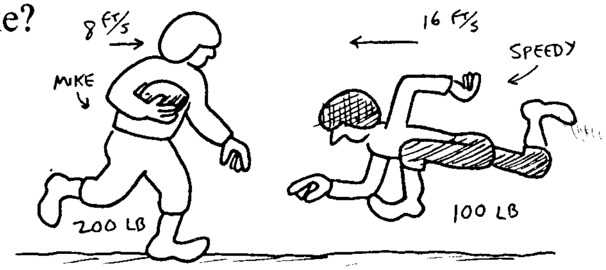


ANSWER: PENETRATION

The answer is: b. Double the distance that gravity acts on the truck rolling down the hill and you double the truck's kinetic energy, which doubles the distance the force can act as the truck penetrates the hay.

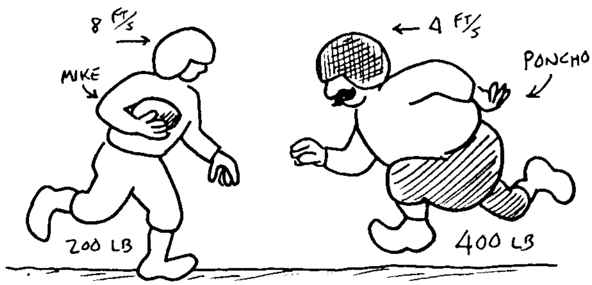
TACKLE

Mighty Mike weighs 200 lbs and is running down the football field at 8 ft/s. Speedy Gonzales weighs only 100 lbs but runs 16 ft/s, while Ponderous Poncho weighs 400 lbs and runs only 4 ft/s. In the encounter who will be more effective in stopping Mike?



a) Speedy Gonzales
b) Ponderous Poncho
c) Both the same

Who is more likely to break Mike's bones?



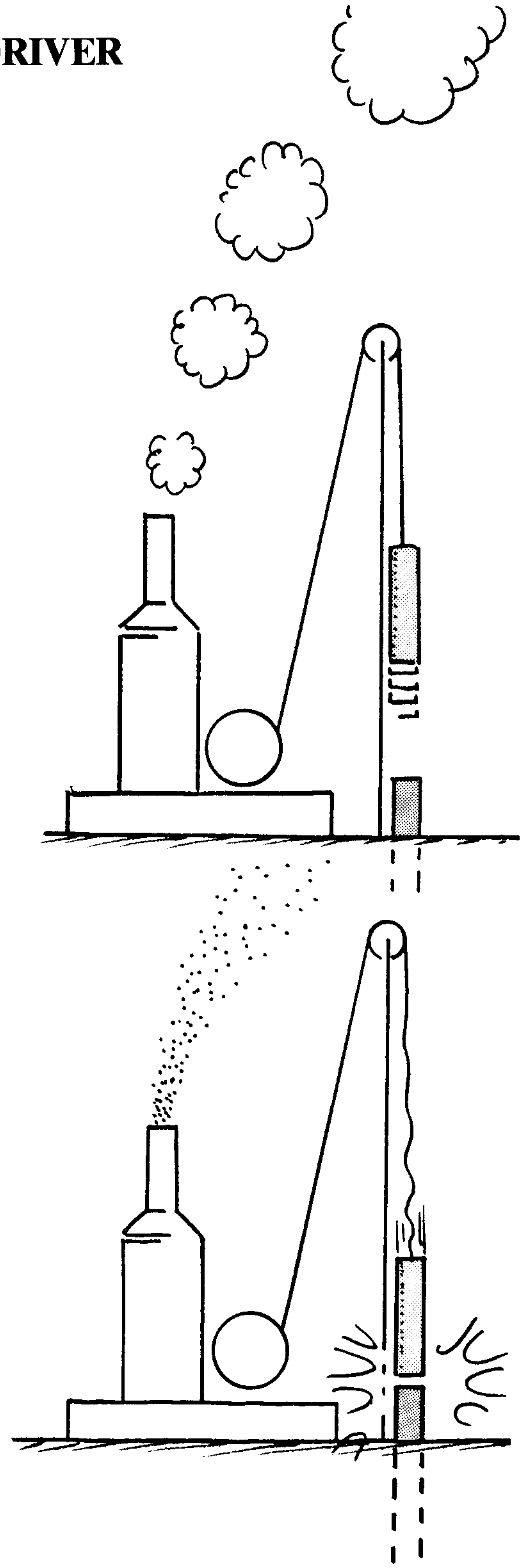
a) Speedy Gonzales
b) Ponderous Poncho
c) Both the same

ANSWER: TACKLE

The answer to the first question is: c. This is straight momentum conservation in action. Note that Mike's momentum is exactly opposed by the momentum of Speedy or Poncho ($200 \times 8 = 100 \times 16 = 400 \times 4$). So the impulse that stops Mike upon collision is the same whether by Speedy or Poncho. Both are equally effective in bringing Mike to a halt.

The answer to the second question is: a. Even though Speedy and Poncho have the same stopping effect or momentum or impulse or punch, Mike will be hurt more by the collision with Speedy (ask any football player). Why? Because Speedy has more kinetic energy than Poncho. Remember GUSH and STOPPING. When you double the speed of a thing it takes double the time to stop, but it takes *four times as much distance to stop.* It penetrates four times as deep. That means it has four times as much kinetic energy. Now Speedy is going four times faster than Poncho. Does this mean he penetrates sixteen times deeper than Poncho, using sixteen times as much kinetic energy? No. Why? Because Speedy has only one fourth as much mass as Poncho, so he has one-fourth of sixteen times as much kinetic energy — four times as much. So Speedy's four-fold energy penetrates four times farther into Mike. That's why it hurts more to be tackled by Speedy than by Poncho.

THE PILE DRIVER

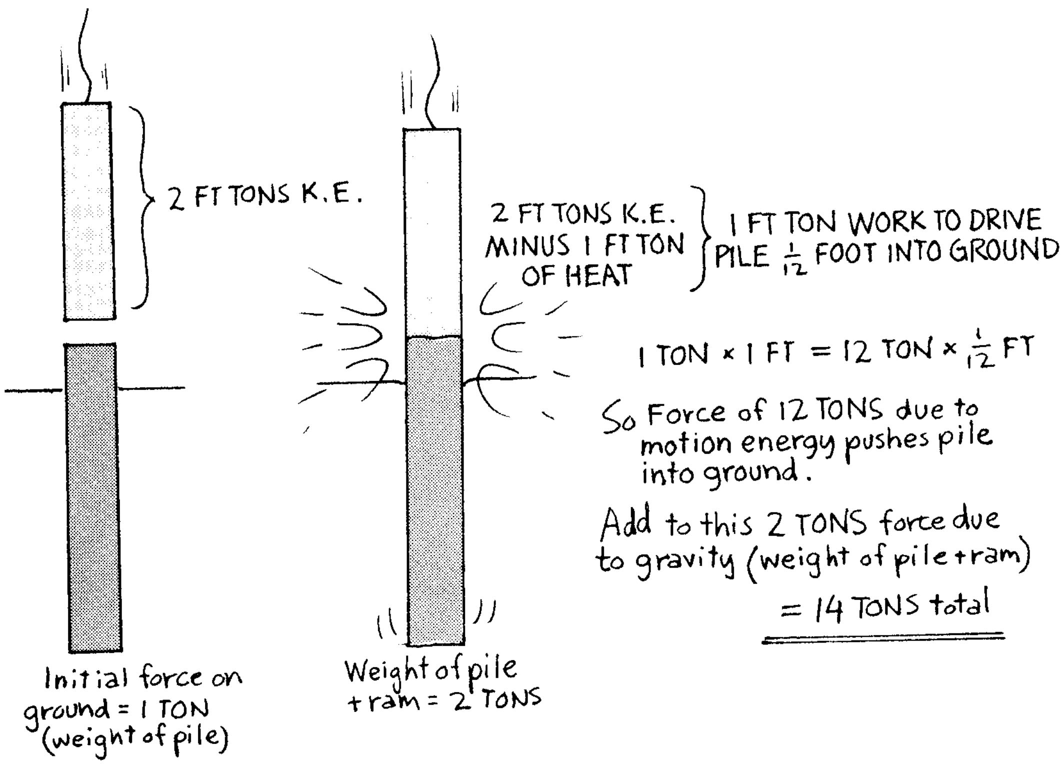


Watching piles being driven into the ground is an interesting sight — the huge machine, the chug and puff and hiss of the engine and then the bang of the hammer. Suppose the hammer and the pile each weigh one ton. Then suppose the hammer drops on the pile from a height of two feet and the impact drives the pile one inch into the earth. What would be the average force of the pile on the ground as it penetrates that one inch?

a) One ton
b) Two tons
c) Twelve tons
d) Thirteen tons
e) Fourteen tons

ANSWER: THE PILE DRIVER

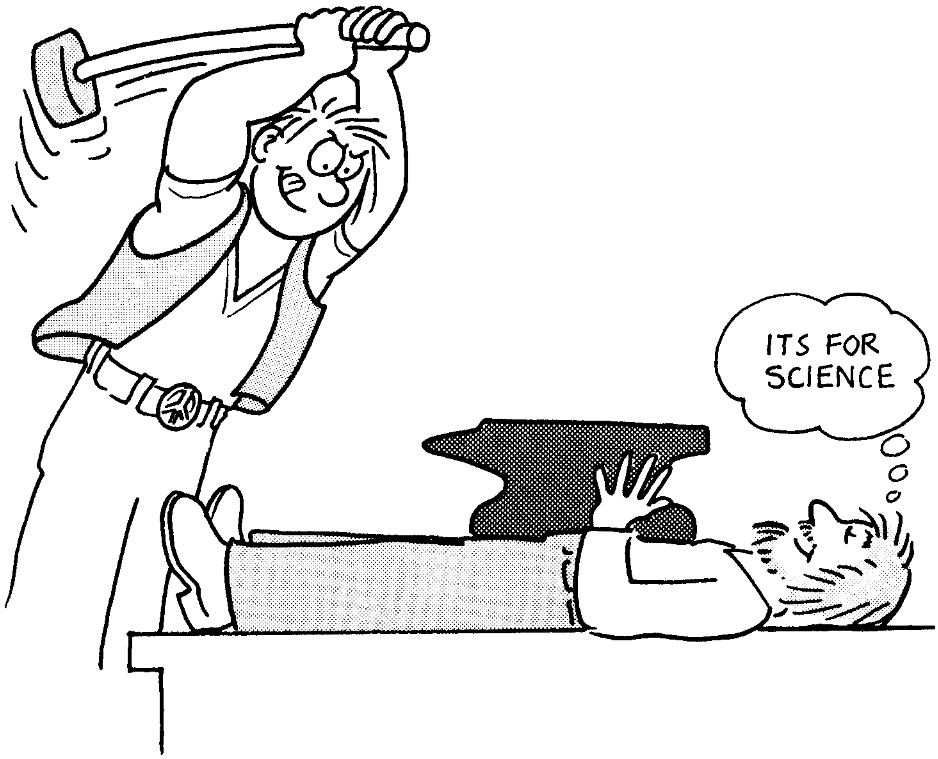
The answer is: e. There are two foot tons of kinetic energy in the hammer when it bangs the pile. Since the hammer and the pile have equal masses, half of that energy is converted to heat by the impact (recall SMUSH AGAIN). That leaves one foot ton of kinetic energy to drive the pile one inch. Now one foot ton is equal to twelve inch tons. That is, a force of one ton pushing one foot does as much work as a force of twelve tons pushing one inch. So does this mean the pile exerts a force of twelve tons on the earth? Even more! The pile pushes on the ground with a weight of one ton even before the hammer hits it, and after the impact the hammer which also weighs one ton momentarily rests on the pile. So there are two more tons — fourteen in all. Does that mean fourteen inch tons of work were done on the earth? Yes, the two extra inch tons came from the weight of the pile and hammer as they went down that last inch. Tricky? A little. That's why engineers earn as much per hour as plumbers — or do they?



SLEDGE

In the classroom lecture demonstration* pictured below, the anvil shields the daring physics professor from most of the sledgehammer's

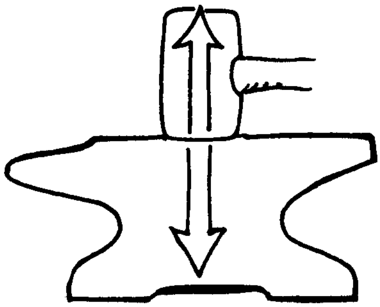
a) momentum
b) kinetic energy
c) . . . both
d) . . . actually neither



*This is a demonstration that I and my students of several semesters ago will likely never forget. I foolishly asked for a student volunteer from the class to man the sledge. In his excitement he missed the anvil and hit my hand, breaking it in two places! I now do the demonstration only with a practiced assistant. —Paul Hewitt

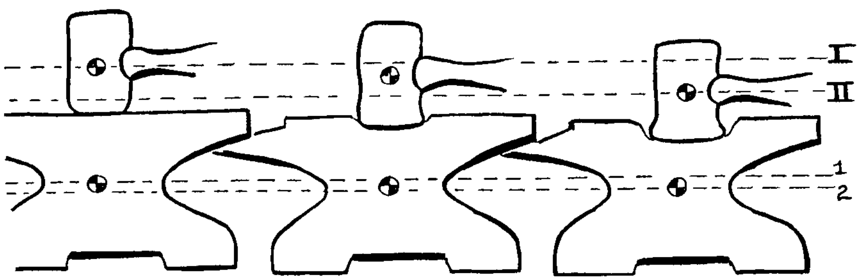
ANSWER: SLEDGE

The answer is: b. Every bit of momentum imparted to the anvil by the sledge is imparted to the professor (and subsequently to the earth that supports him). The anvil doesn't shield the professor from the sledge's momentum — not a bit. The shielding of kinetic energy is a different story. A significant fraction of the sledge's kinetic energy never gets to the professor — it is absorbed by the anvil in the form of heat. Have you ever noticed that a hammer head gets warm after you have been hammering vigorously? Heat is the graveyard of kinetic energy.



We can be a bit more insightful about this and investigate the goings on during the impact between the sledge and anvil. During impact the force on the anvil at every instant is equal and opposite to the force on the sledge at that same instant. The sledge acts on the anvil just as long and just as hard as the anvil acts (reacts) on the sledge. Therefore the impulse or punch that stops the sledge is exactly equal to the impulse or punch that goes into the anvil, and then into the professor. If the sledge comes to a dead stop, the impulse must have cancelled all the sledge's momentum, and that same impulse must put the same amount of momentum into the anvil. So we see that the anvil gets every bit of the momentum the sledge loses — the momentum is completely transferred from the sledge to the anvil. Of course, the newly acquired momentum does not make the anvil move very fast because it has much more mass than the sledge.

Now consider kinetic energy. When we analyze momentum we think about the *time* during which forces act, but when we analyze energy we think about the *distance* through which forces act. That's because the energy a body acquires is equal to force multiplied by the distance over which the force pushes the body. Consider in the sketch the relative distances that the sledge and anvil move during impact. Note that the sledge moves from I to II, while the anvil only moves from 1 to 2, which is a



smaller distance.* Equal forces but unequal distances result in unequal changes in kinetic energy — the sledge loses more kinetic energy than the anvil gains.

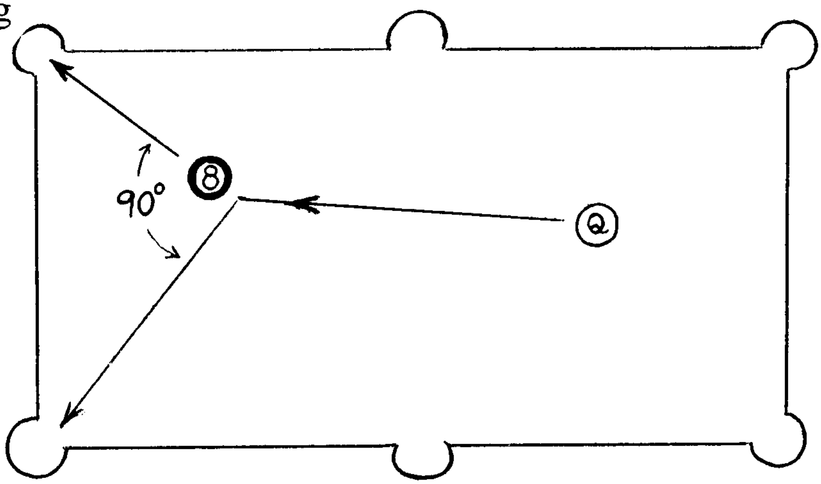
So while all the momentum of the sledge is transferred to the anvil and then to the professor, all the kinetic energy is not. The professor is shielded from the kinetic energy and he will return to lecture again.

*Another way to see this is to reason that during impact, the sledge's speed drops from about 30 mph to 1 mph, while the anvil's speed increases from 0 mph to 1 mph. Although they both end up with the same speed, the sledge was moving faster than the anvil at all other instants and therefore had to move farther during the impact.

SCRATCH

(This problem is more advanced than most in this book, and involves the conservation of both energy and momentum, with a bit of vector addition to boot.) The cue ball and "8" ball are located on a pool table as illustrated. If an inexperienced player shoots the cue and successfully sinks the "8" in the corner pocket is there much danger that the cue ball will be deflected into the other corner pocket? A scratch is when the cue ball sinks in any pocket.

a) In the illustrated positions there is a great danger of scratching
b) In the illustrated positions there is little danger of scratching

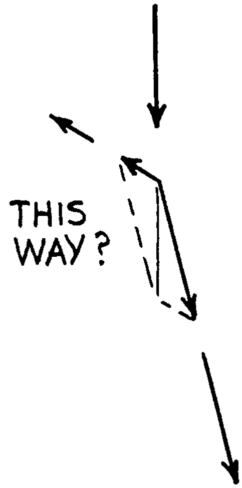


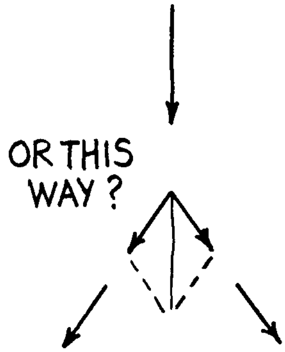
ANSWER: SCRATCH

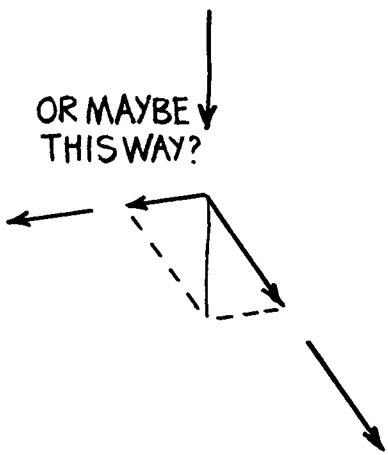
The answer is: a. Every pool shark knows that when the "Q" ball hits the "8" ball, the balls move off in directions about 90 degrees apart, that is, they bound off at right angles to each other. From the illustrated position of the "8" ball, the corner pockets are about 90 degrees apart, so there is great danger of scratching.

But why do the balls fly off at right angles? The balls have (or should have) equal mass so their momentum is proportional to their velocity. Therefore, the vector sum of the velocity of the "Q" ball plus the "8" ball after the collision should add up to the original vector velocity of the "Q' ball before the collision. But as the sketch shows there are many ways to pick a pair of velocities which will add up to equal the original "Q" ball velocity. Which pair should you choose?

Momentum is not the only thing to consider, for the balls are elastic and the sum of the kinetic energies of the balls after collision is about equal to the original kinetic energy of the "Q" ball. Now the kinetic energy of a ball is proportional to the square of its velocity and since the balls have equal mass, the square of the velocity of the "Q" ball after the collision plus the square of the velocity of the "8" ball after the collision should add up to equal the square of the original velocity of the "Q" ball before the collision. Now by the rules of vector addition, we know the vector velocity of the "8" and "Q" balls form the sides of a parallelogram and from the Law of Momentum Conservation the diagonal of the parallelogram is equal to the original velocity of the "Q" ball. And by conservation of kinetic energy, we know the sum of

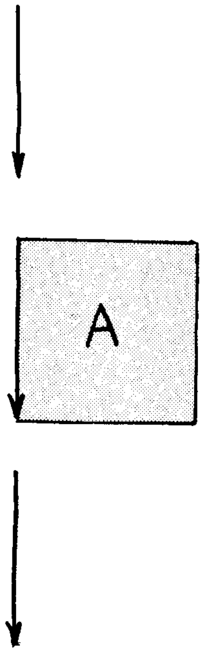


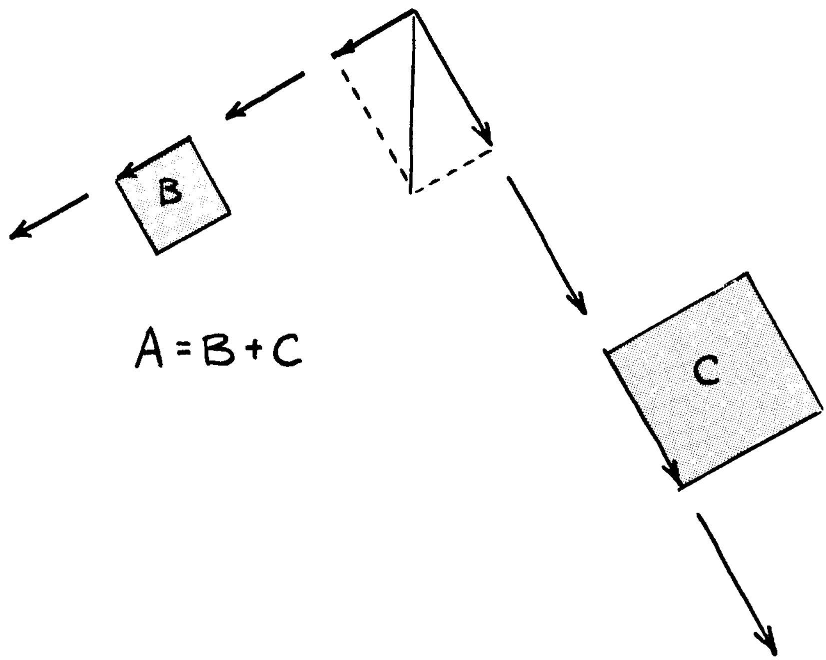




the squares of the sides of the parallelogram must equal the square of the diagonal. But that means the angle between the sides of the parallelogram must be a right angle! Remember Pythagoras.

So, the balls fly off in directions 90 degrees apart. Why did we hedge our bet and say ABOUT 90 degrees apart? Because the collision is not perfectly elastic and some of the original kinetic energy becomes heat. Also, there is some friction between the balls and the pool table. So the momentum and energy of the balls AFTER the collision does not exactly equal the momentum and energy BEFORE the collision. Also, some of the energy might go into making one of the balls spin after the collision. By taking advantage of these effects an experienced player can always find a way to shoot the "Q" ball without scratching.

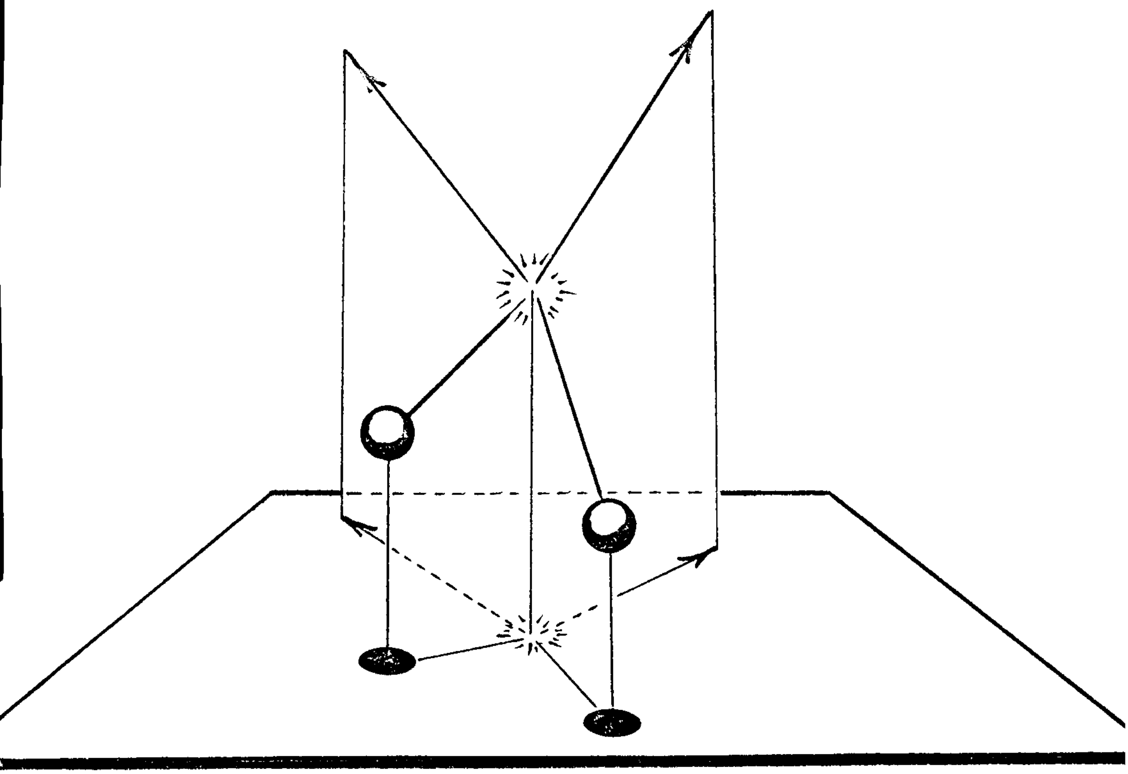




HEAVY SHADOWS

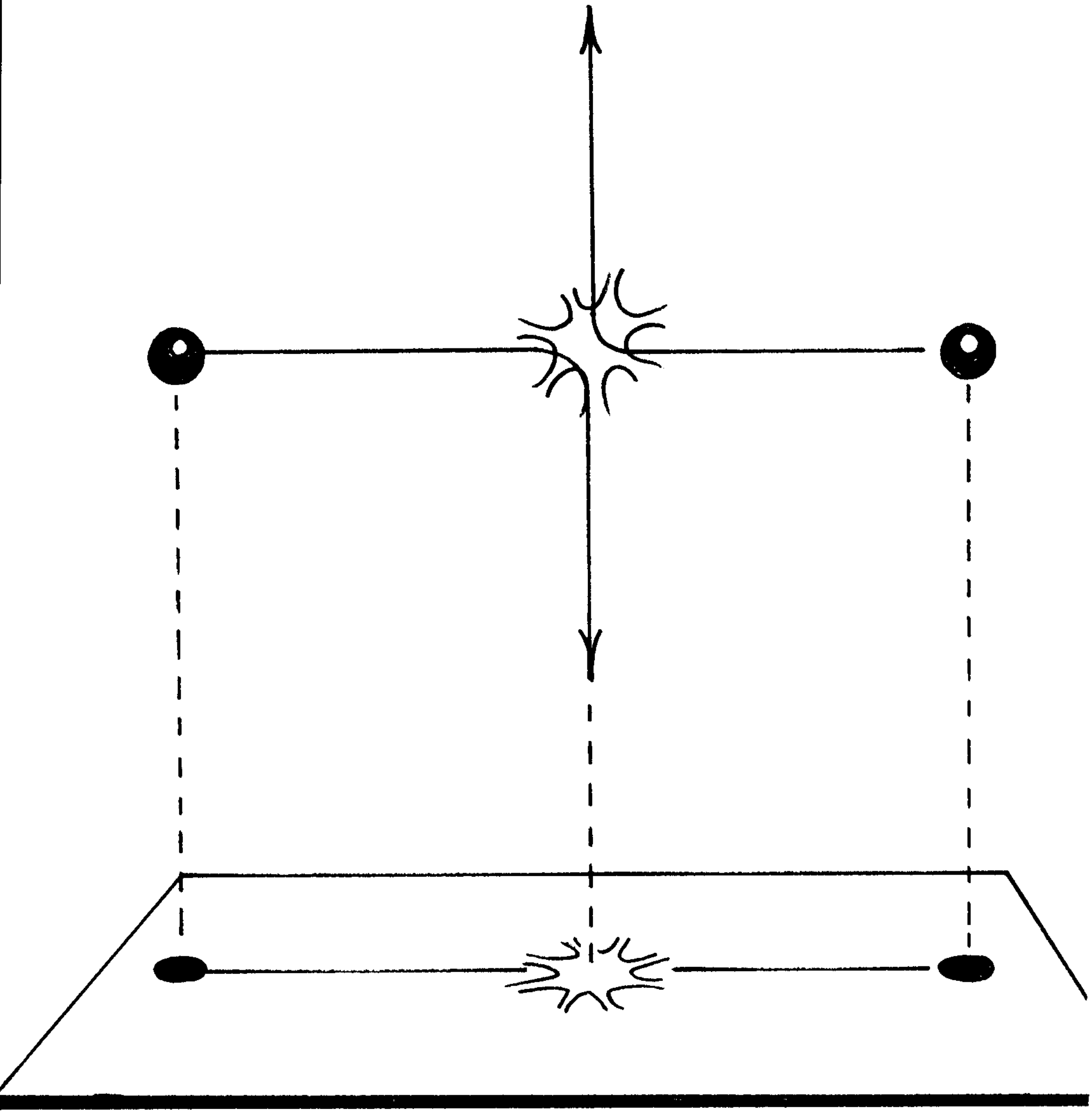
(This, too, is somewhat advanced.) Suppose that two elastic balls moving through three-dimensional space collide and rebound, conserving both kinetic energy and momentum. The balls cast shadows, and these shadows, moving over a flat two-dimensional surface come together, collide and rebound. Now pretend the shadows have mass. Suppose the shadow of a ball has a mass proportional to the mass of the ball. Then, the colliding shadows

a) conserve kinetic energy
b) conserve momentum
c) conserve both kinetic energy and momentum
d) conserve neither kinetic energy nor momentum

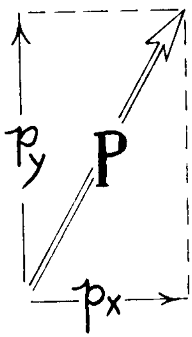


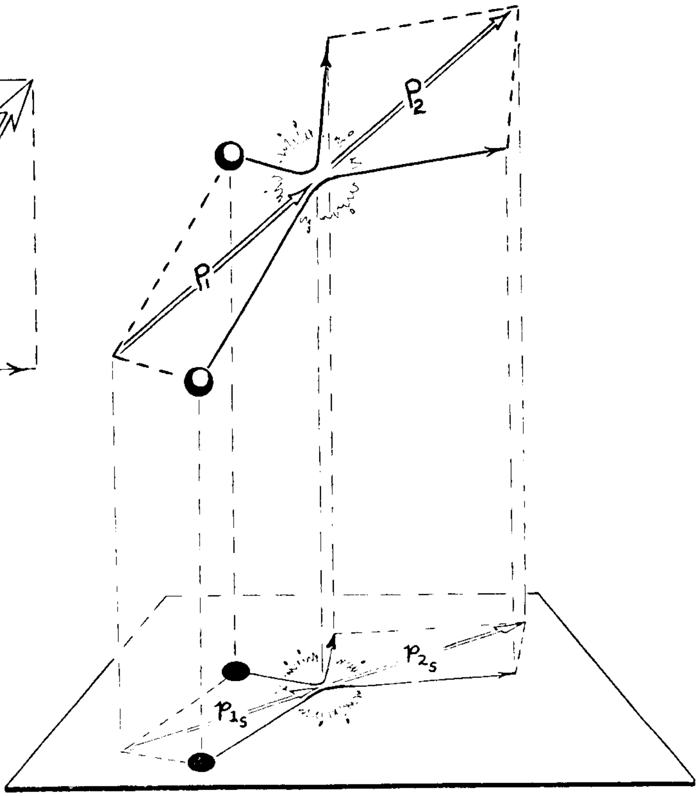
ANSWER: HEAVY SHADOWS

The answer is: b. The shadows cannot conserve kinetic energy. Suppose the balls move as illustrated below. Then the shadows are stationary after the collision, so energy cannot be conserved.



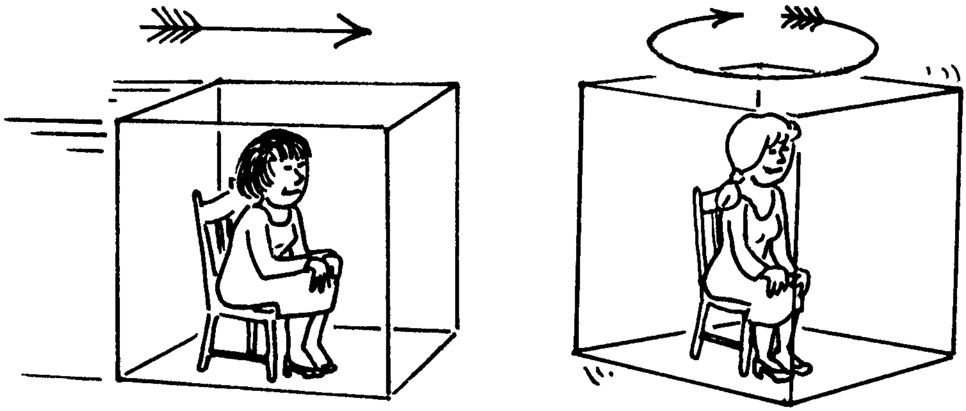
Now for momentum. The momentum of the balls before collision adds up to some total momentum vector P_1 and after collision the two momenta add up to P_2. By conservation of momentum $P_1 = P_2$. The shadow or projection of P_1 on the flat surface is p_1 and the shadow of P_2 is p_2. Then $p_1 = p_2$. Why? Because the shadows of parallel sticks (or vectors) of equal length are equal. What if the balls were not perfectly elastic? Would shadow momentum still be conserved? Yes. All collisions — elastic or inelastic — conserve momentum, but only elastic collisions conserve kinetic energy. So what does it mean if shadows conserve momentum? It means we can think of a momentum like P as made up of components, like a horizontal and vertical component or an X and Y component, and EACH of these components is itself conserved, just as if the other component did not exist.





ABSOLUTE MOTION

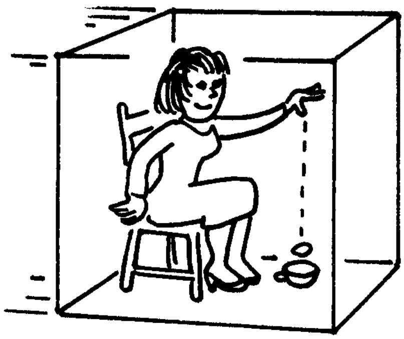
A scientist is completely isolated inside a smoothly-moving box that travels a straight-line path through space, and another scientist is completely isolated in another box that is spinning smoothly in space. Each scientist may have all the scientific goodies she likes in her box for the purpose of detecting her motion in space. The scientist in the



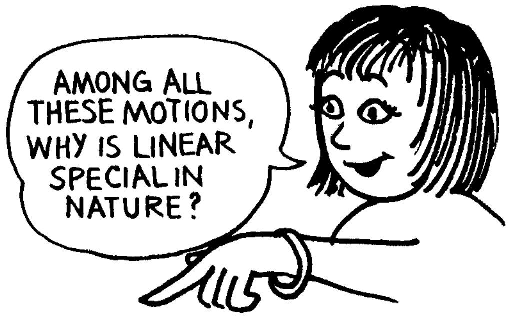
a) traveling box can detect her motion.
b) spinning box can detect her motion.
c) . . . both can detect their motions.
d) . . . neither can detect their motions.

ANSWER: ABSOLUTE MOTION

The answer is: b. This question is the rotational counterpart to INERTIA. If your non-spinning box is moving smoothly in a straight-line path through space, you cannot sense its motion. For example, if you drop a coin above a cup it will fall directly into the cup whether or not your box is moving. Try it in a uniformly moving train or airplane. But if the box stops or starts or turns or jerks, you can sense motion. If the box accelerates you know that you're moving — but if it doesn't accelerate you can't tell. Do all the physics experiments that you care to in your uniformly and linearly moving box and you still can't tell. Even look outside and witness a moving background and you can't say for sure whether you or the background is moving. All you can say is you are moving relative to the background, or equivalently, vice versa. Linear motion is relative.



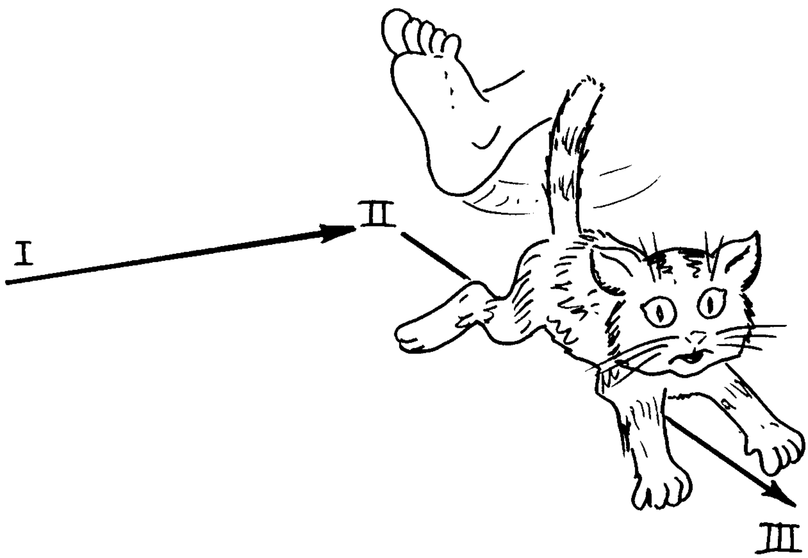
But the spinning box is different. You know you're moving without consulting any background, and if the spin rate is fast enough you need only consult your stomach (have you ever become nauseous on a rotating carnival ride?). And if your box is spinning very slowly you can still tell by watching the precession of a swinging pendulum. Rotational motion is absolute.



Why is one type of motion relative and the other absolute? Why are not both either relative or absolute? Or why not vice versa? After all, according to the ancient Greeks, circular motion is most preferred by the gods. These are deep and unanswered questions. All we know is that in our universe linear motion is relative and rotational motion is absolute. Were this not so the laws of motion would be very unlike those we live with now. But that does not explain why things are the way they are. That which is far away and exceedingly deep — who can find it out? Perhaps you!

TURNING

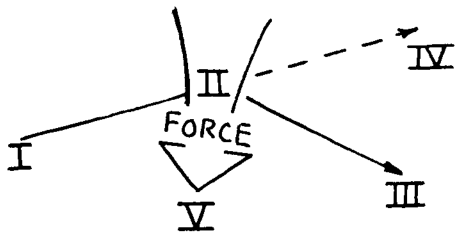
A cat runs across the floor from I to II to III without increasing or decreasing his speed. He only changes his direction of motion at II. Can we say for sure that a force was exerted on the cat at II?



a) Yes, there had to be a force on the cat at II
b) Not necessarily, since no change in the cat's speed occurred

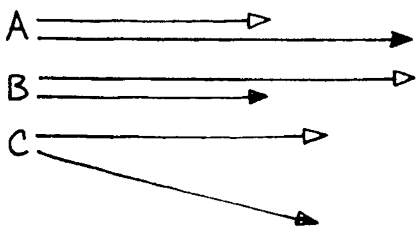
ANSWER: TURNING

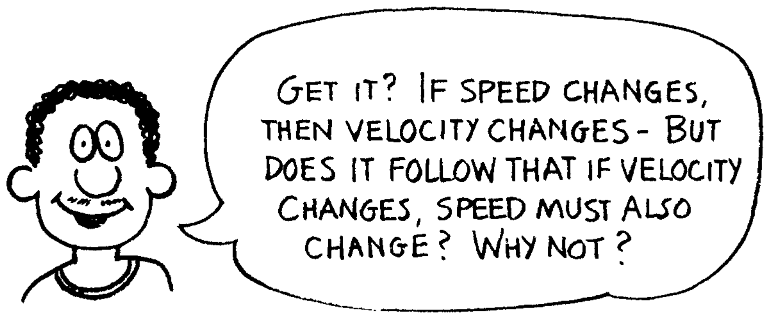
The answer is: a. There had to be a force on the cat at II. If there were no force the cat would keep going in a straight line and go to IV instead of III. Pehaps someone kicks the unfortunate cat at II in direction V. The force of the kick turns the cat toward III. Or the cat could have turned itself by pushing on the floor with its feet. However, if the cat were on frictionless ice at II it couldn't muster a turning force. No force, therefore no turn — a "skidout."



But why didn't the force change the cat's speed? Because it was a sideways force. A force pushing forward makes a thing go faster. A reverse force makes a thing slow down, stop or go backwards. But a sideways force makes a thing turn.

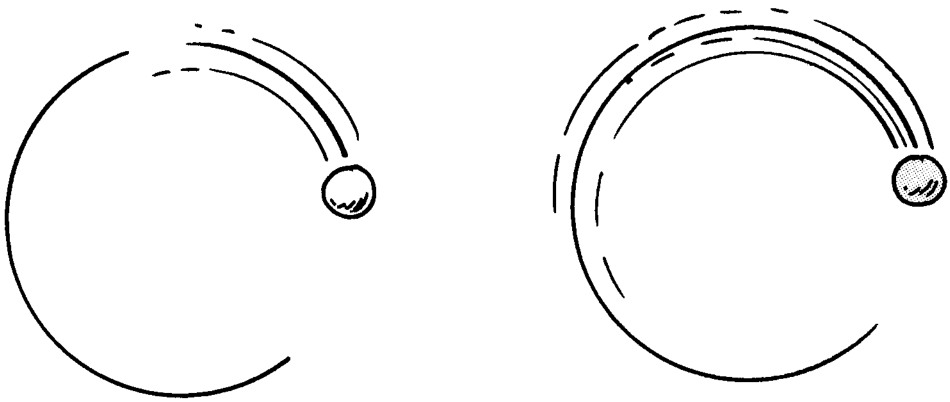
Physicists like to say a force always changes a thing's velocity, but does not always change its speed. What is velocity? Velocity is the "arrow" that represents a thing's motion. Physicists like to call the arrow a vector. If a thing goes faster it gets a new longer arrow, sketch A. If it goes slower, the result of deceleration or negative acceleration, it gets a new shorter arrow or vector, sketch B. And if it turns, it gets a new velocity vector which might be just as long as the original one but points in a different direction. That means same speed, but in a different direction, sketch C. So we see in this example that velocity can change while speed does not.





FASTER TURN

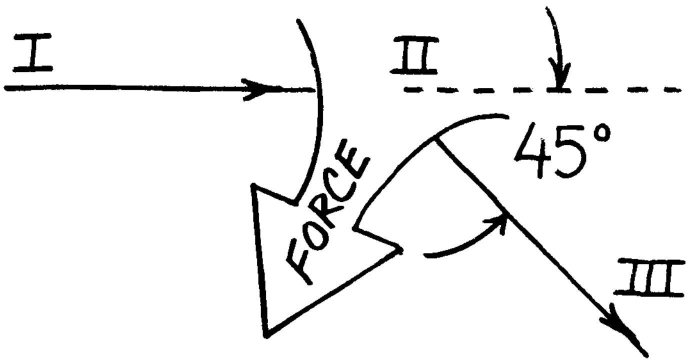
Suppose that two identical objects go around circles of identical diameter, but one object goes around the circle twice as fast as the other. The turning (centripetal)force required to keep the faster object on the circular path is



a) the same as the force required to keep the slower object on the path
b) one-fourth as much as the force required to keep the slower object on the path
c) half as much as the force required to keep the slower object on the path
d) twice as much as the force required to keep the slower object on the path
e) four times as much as the force required to keep the slower object on the path

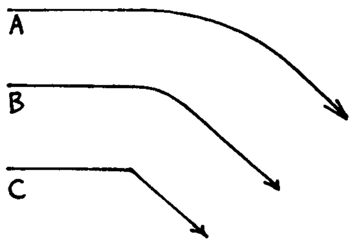
CAN IT BE TOLD

An object with a known mass, say one kilogram, is moving from I to II with a known speed, say one meter per second. At II a force acts on the object. The force does not change the object's speed, but does change its direction of motion by 45 degrees. Is it theoretically possible to calculate how strong the force was?

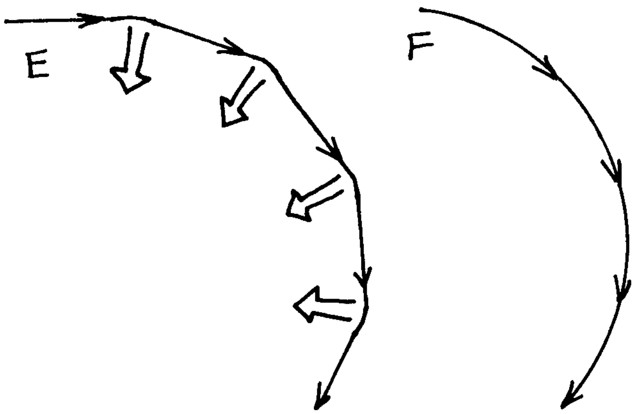


a) Yes, the strength of the force can be calculated (though I might not know how to do the calculation).
b) No, the force cannot be calculated by anyone.

ANSWER: CAN IT BE TOLD

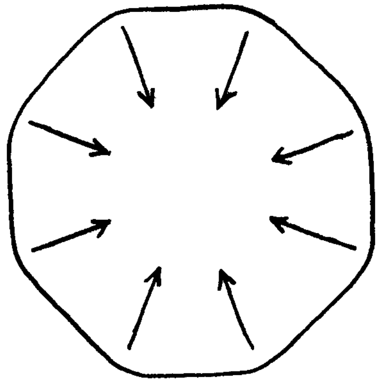


The answer is: b. You can't tell. The story here is very much like the story in ROCKET SLED. The turn could be made by a small force acting for a long time or a large force acting for a short time. If the force is small and the time long, the turn will be gradual, see sketch A, but if the force is strong and the time is short the turn will be abrupt, see sketch B. If the turn is instantaneous, as in sketch C, the force would have to be infinitely large. So, perfectly sharp turns do not exist in nature.



If an object goes around a bent path, like sketch E, the force is on some of the time and off at other times. The force is on in the curves, and off in the straight parts. Often it is convenient to talk about the average force. If the object goes around a smooth circular path, like F, however, then the force is exactly equal to the average force.

ANSWER: FASTER TURN

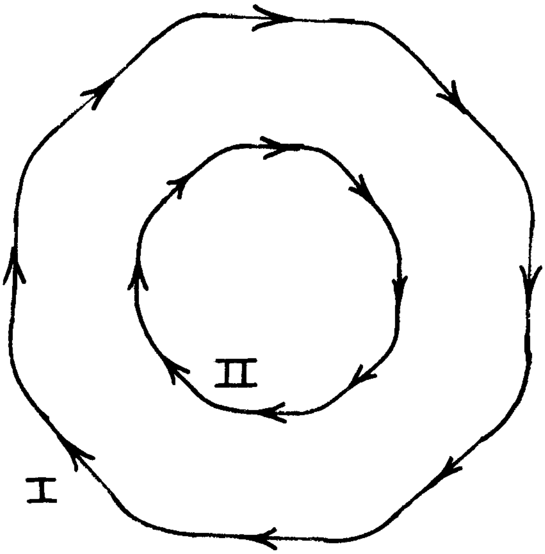


The answer is: e. Think of the circle as a bent path with many sides. As the object runs around the path it must get little kicks which bend the path. Now if the object begins running around twice as fast you have to kick it twice as hard to bend the path by the same amount. So you might think the average force on the object would be doubled. But there is more. If it runs twice as fast it comes to each bend twice as often. So you have to kick it twice as hard twice as often. That increases the average force four times. If it goes around three times as fast you must kick it three times as hard three times as often. That would increase the average force nine times.

There is a road near Lew Epstein's house with a sharp curve in it. The highway sign warns 20 miles per hour, but one day Lew decided to cheat a little and do 30 mph. What harm could an extra 10 mph do? In going from 20 to 30 he had only increased his speed 1.5 times. But increasing his speed 1.5 times increases the required centripetal force on his car $1.5 \times 1.5 = 2.25$ times. So a 50% speed increase requires a more than 100% increase in centripetal force — which didn't happen on loose gravel and Lew's car ran off the road!

SHARPER TURN

An object goes around bent path I with a speed of one mile per hour. An identical object goes around bent path II with the same speed. The diameter of path II is half the diameter of path I. The average force required to keep the object moving along path II is

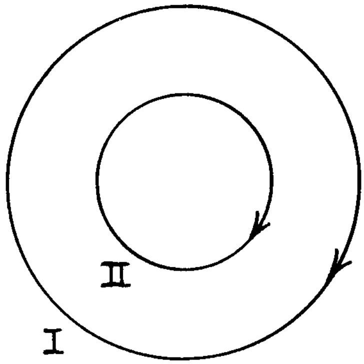


a) the same as the average force on the object in path I
b) half the average force on the object in path I
c) double the average force on the object in path I
d) four times the average force on the object in path I
e) one-fourth of the average force on the object in path I

ANSWER: SHARPER TURN

The answer is: c. The turn angles, mass, and speed of the objects moving in path II and path I are all exactly the same. So you might think the average force would be the same. But it is not. Why? Because you must average the force. On path II there is less time between bends, half as much time as on path I because path II is only half as long as path I. So there is half as much time to average over on path II and that makes the average force on path II twice as big as the average force on path I. Like a dollar averaged over twenty minutes is a nickel per minute, but averaged over ten minutes is a dime per minute.

Now if path I and II were made into perfect circles, all that has been said is still true. That is, if identical objects move with identical speeds the force on the object travelling in the smaller circle is larger. If the diameter of the small circle is one-half or one-third the diameter of the large circle, the force on the object moving in the small circle is twice or three times the force on the object moving in the large circle.



When an object moves in a circle the turning force, which always is exerted sideways, will always be directed towards the circle's center. The turning force is called centripetal force. The turning force does not keep the object going, it only keeps it turning, that is, keeps it on the circular path.

Everyone knows that as a turn gets sharper a train or motor car has a harder time going around it. But now you know why. The sharper the turn, the smaller the turning circle. The smaller the turning circle, the larger the required centripetal force. If this centripetal force is not exerted, the result is a derail or skidout.

Of course, if the objects have different masses that too must come into the story. The force needed to turn an object will increase in proportion to its mass.

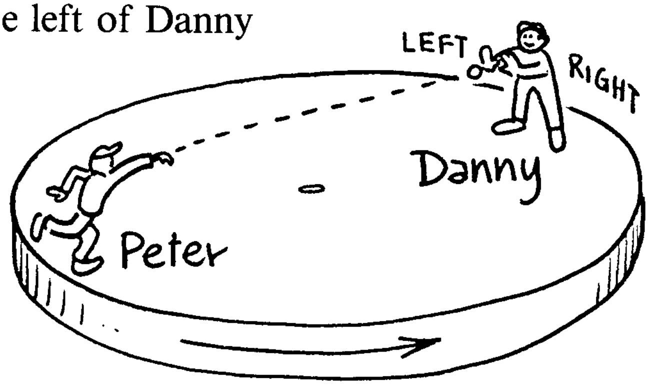
In symbolic notation, the centripetal force F required to keep an object of mass m moving at speed v along a curved path of radius r is

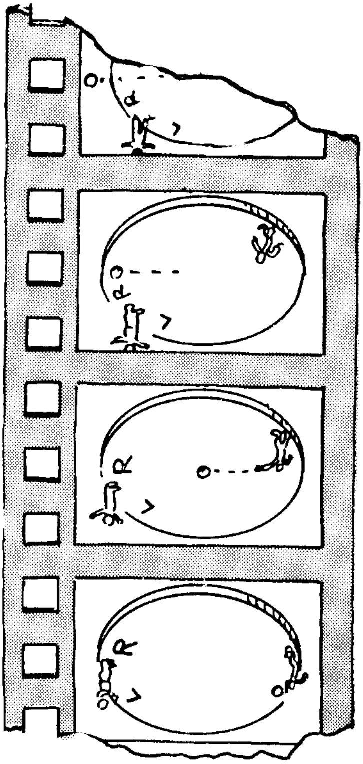
$$F = m\frac{v^2}{r}$$

CAROUSEL

Peter and Danny are standing on a carousel which is turning as illustrated. Peter throws a ball directly towards Danny.

a) The ball gets to Danny
b) The ball goes to the right of Danny
c) The ball goes to the left of Danny





ANSWER: CAROUSEL

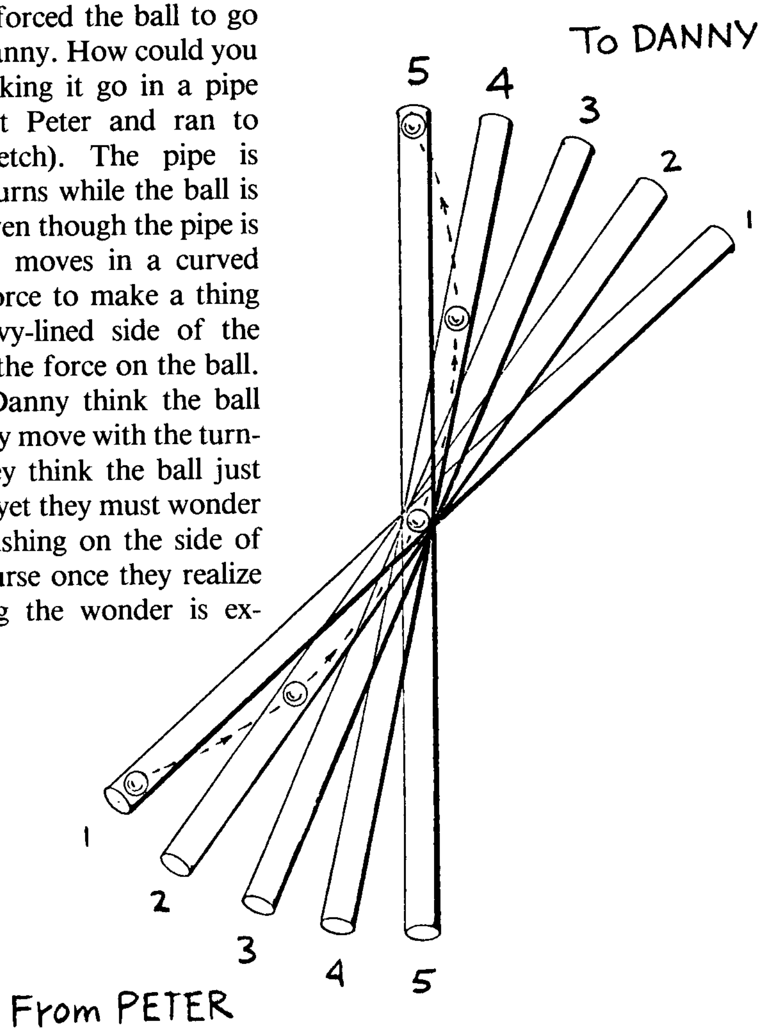
The answer is: b. The ball might start going directly towards Danny, but by the time it gets that far he and the turning table will move, so the ball will miss him. The film shows how the table turns and it shows "R" is moved into the place which was previously occupied by Danny. So the ball goes on the "R" side of Danny.

Moreover, even if Peter aims the ball at Danny it does not even start going towards Danny when Peter throws it. Why? Because Peter is not standing still. He is moving with the carousel. The ball carries with it Peter's velocity, that further deflects the ball towards "R."

When you live on a turning world things do not go in the direction they are aimed. In fact, they don't even SEEM to go in straight lines.

This deflection has a name. It is named after one of the first persons to study it — Coriolis. There is even a slight Coriolis effect on things moving over the earth because the earth is truly a turning world.

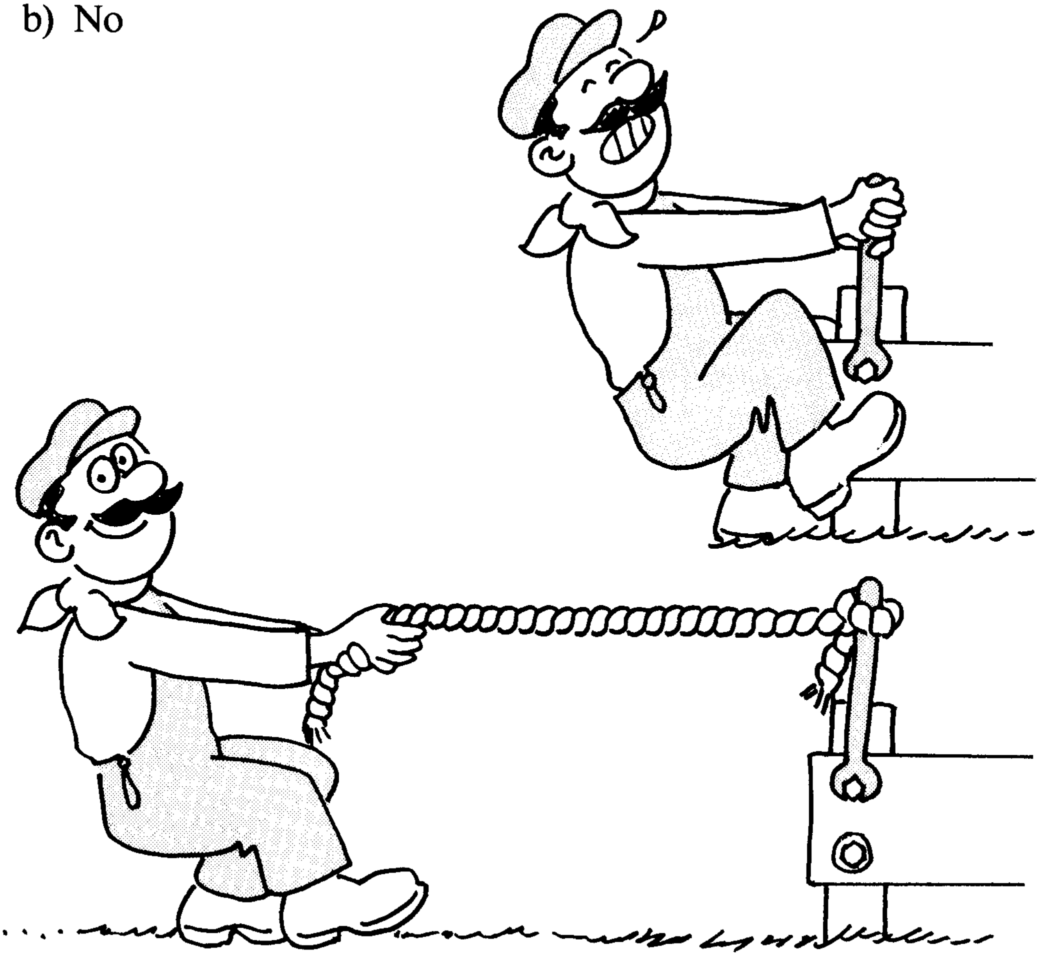
Suppose you forced the ball to go from Peter to Danny. How could you force it? By making it go in a pipe which started at Peter and ran to Danny (see sketch). The pipe is straight, but it turns while the ball is on its way. So even though the pipe is straight the ball moves in a curved path. It takes force to make a thing curve. The heavy-lined side of the pipe must exert the force on the ball. Do Peter and Danny think the ball curves? No. They move with the turning pipe. So they think the ball just goes straight — yet they must wonder why it keeps pushing on the side of the pipe. Of course once they realize they are turning the wonder is explained.



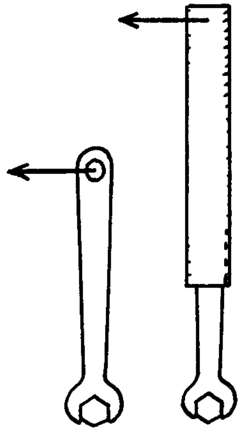
TORQUE

Harry is finding it very difficult to muster enough torque to twist the stubborn bolt with a wrench and he wishes he had a length of pipe to place over the wrench handle to increase his leverage. He has no pipe, but he does have some rope. Will torque be increased if he pulls just as hard on a length of rope tied to the wrench handle?

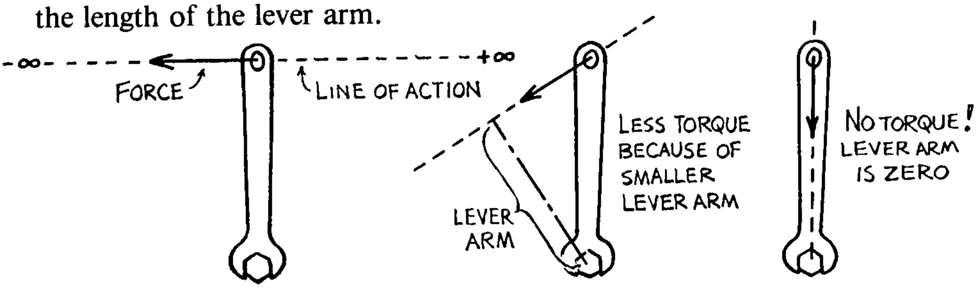
a) Yes
b) No



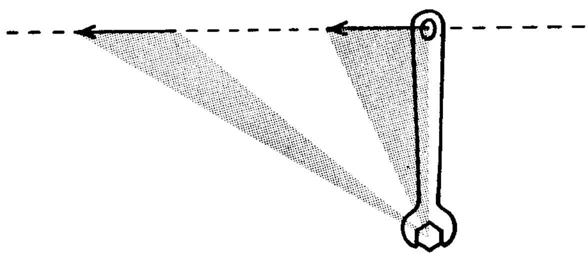
ANSWER: TORQUE



The answer is: b, no. The twisting force or torque that is applied to the stubborn bolt depends not only on the applied force but also on the length of the lever arm upon which the force acts. This relationship can be visualized by recalling your experiences with wrenches or see-saws. The greater the leverage, the greater is the torque. By attaching the rope to his wrench, Harry increases the distance from the bolt to the location of the applied force, but he doesn't increase the lever arm. That's because the lever arm is not the distance from the pivot point (bolt) to the applied force, but rather the distance to the *line of action* of the applied force. The lever arm is always at right angles to the line of action of the applied force. It is also the shortest distance between the line of action and the pivot point. When Harry uses the rope he does not change the length of the lever arm.



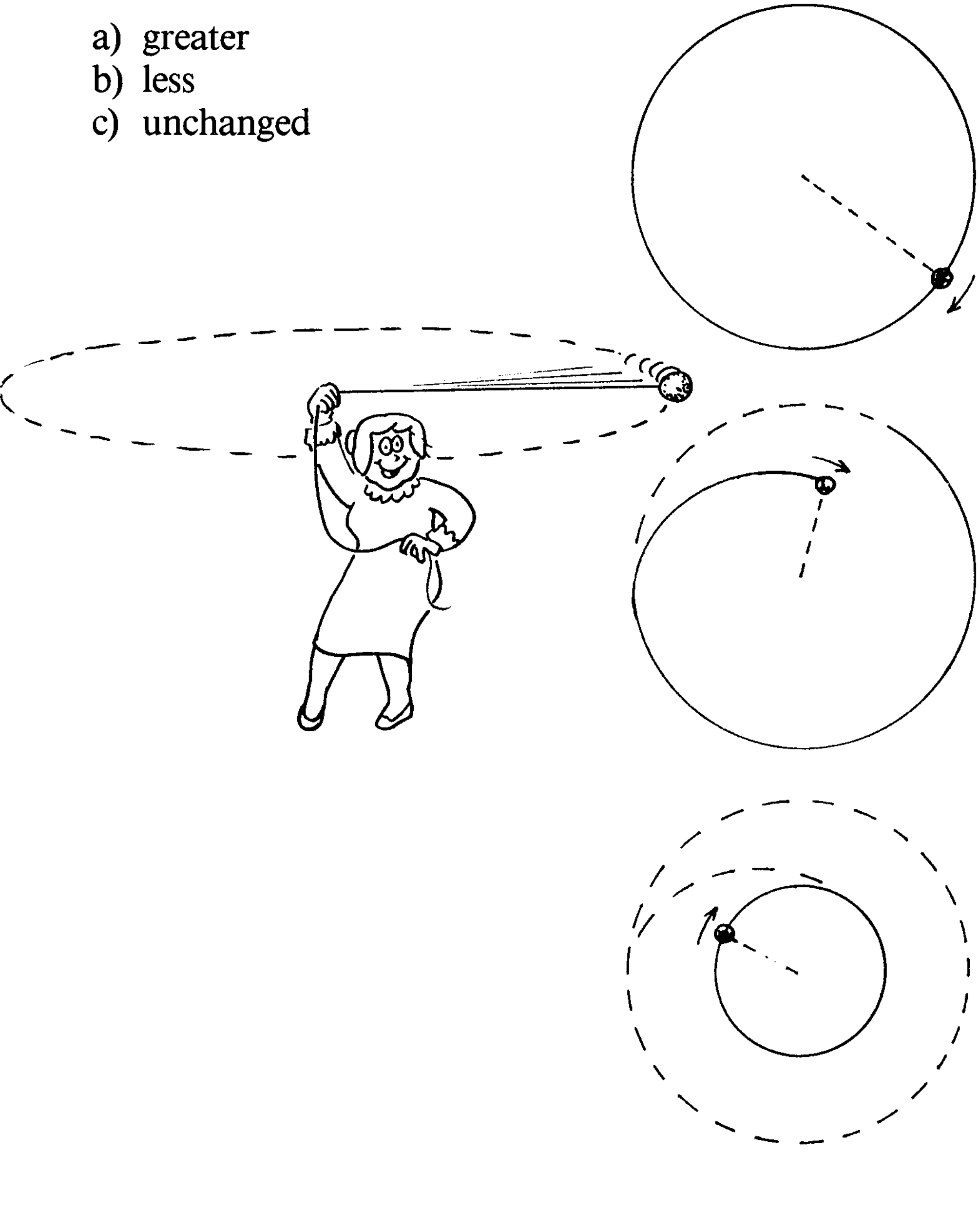
By definition, torque is equal to force multiplied by the lever arm. We can picture torque geometrically — it's twice the area of a particular triangle. Let the altitude of the triangle be the lever arm and the base of the triangle be the force vector. Remember that the area of a triangle is one-half the altitude multiplied by the base. In our case, altitude = lever arm, and base = force. So the area is equivalent to half the torque. From the sketch you can see that whether or not the force is applied directly to the wrench handle or from a rope tied to the wrench handle, the area of the triangle formed by the applied force and the pivot point is the same in both cases (same base and altitude), so the torque is the same.



BALL ON A STRING

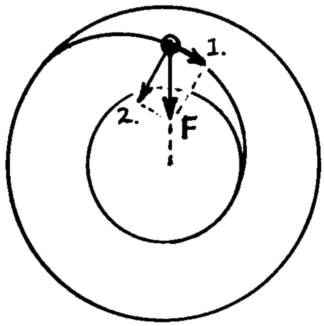
A ball held by a string is coasting around in a large horizontal circle. The string is then pulled in so the ball coasts in a smaller circle. When it is coasting in the smaller circle its speed is

a) greater
b) less
c) unchanged



ANSWER: BALL ON A STRING

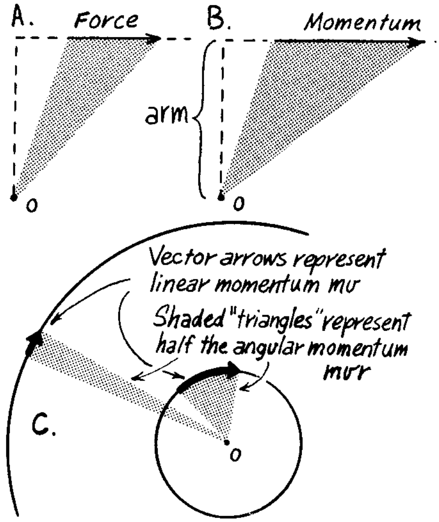
The answer is: a, greater. When the ball is moving in a circular path of constant radius the pull of the string does not speed it up — it coasts at constant speed. But when the ball is pulled into a smaller circle, the force of the string speeds it up. Why? Because in the first case where the radius remains constant the string is always pulling at right angles to the motion of the ball — in other words the pull is always sideways and serves only to keep the ball's direction of motion changing — into a circular path instead of a straight line (which would be the case if the string broke).



But when the ball is being pulled in from a large circle to a smaller circle the force of the string is not exactly sideways to the ball's motion. We can see in the sketch that the force of the string has a component of force in the direction the ball is moving. In the sketch we see that Component 1 acts to increase the speed, and Component 2 simply changes the ball's direction of motion.

There is an ingenious way to determine this increase in speed. It depends on the idea of angular momentum, which for a body of mass m moving at speed v at a radius r is the product mvr. Just as a force is required to change the linear momentum of a body, a torque is required to change the angular momentum of a body — if no torque acts on a rotating body, its angular momentum cannot change. Does the string exert a torque on the ball? It does only if the force acts through a lever arm (recall TORQUE). Is there a lever arm? No, the line of action of the force passes straight through the pivot point. There is no torque, and therefore no change in angular momentum. The ball has the same angular momentum mvr when it arrives at the small circle that it had on the large circle. Since the product mvr doesn't change, any decrease in radius is exactly compensated by an increase in speed. Say if r decreases by half, then v increases by two; if r is pulled in to a third its initial value, the speed triples. This holds true in the absence of a torque, which would otherwise change the angular momentum.

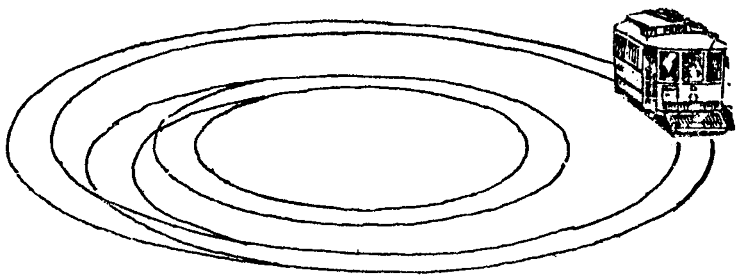
We can represent this idea pictorially, just as we did for torque: Recall that torque is force $\times$ lever arm, and can be pictured as twice the area of the triangle formed by the force vector and lever arm, Sketch A, opposite page. So too, angular momentum $= mvr =$ (linear momentum mv) $\times$ (lever arm r) can similarly be represented by twice the area of the triangle formed by the linear-momentum vector and the lever arm, Sketch *B.* If no torque acts on any rotating system, its angular momentum will not change. In the case of our circling ball, the angular momentum is the same on the outer circle as it is on the inner circle. That means the area of the triangle formed by the linear momentum and the pivot point doesn't change. Like if the radius of the smaller circle is one third the radius of the larger circle, then the linear momentum (mv) of the ball on the smaller circle must be three times larger than when on the large circle. That means it goes three times as fast. Note that in this way the area of the angular momentum triangle comes out to be the same for both circles, Sketch *C.*

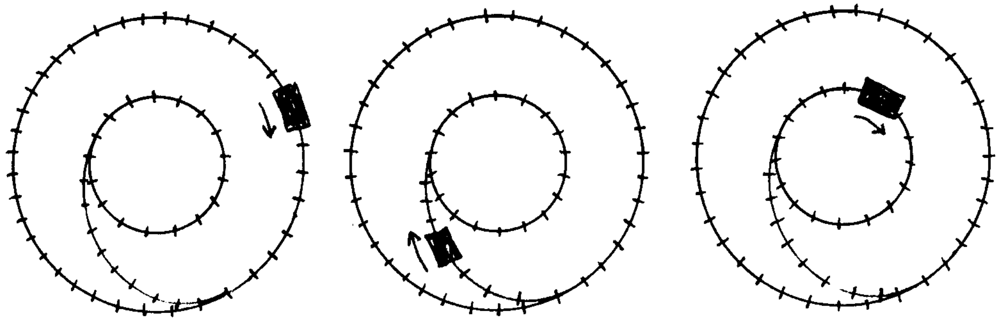


SWITCH

A streetcar is freely coasting (no friction) around the large circular track. It is then switched to a small circular track. When coasting on the smaller circle its speed is

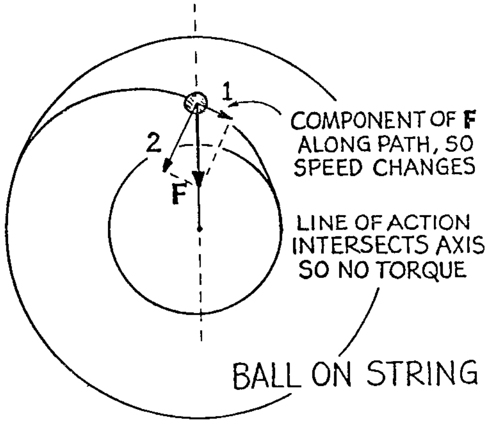
a) greater
b) less
c) unchanged



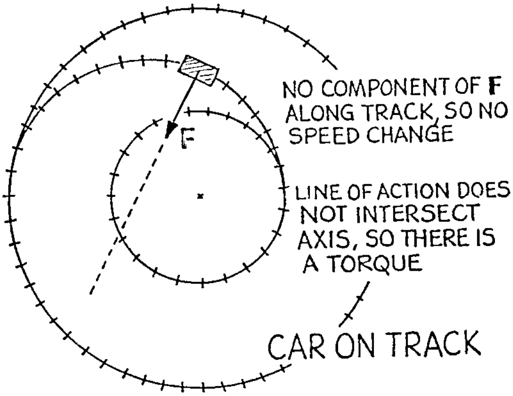


ANSWER: SWITCH

The answer is: c, unchanged. BALL ON A STRING gained speed when it was pulled in to a smaller circle because there was a force component in its direction of motion. But this is not the case for the car on the track. If the track were perfectly straight the track could exert no force to speed the car up (or slow it down if it is frictionless). A curved track, however, does exert a force that changes the state of motion of the car — a sideways force that makes the car turn. But this sideways force has no component in the coasting car's direction of motion. So the track cannot alter the speed of the freely-coasting car.



Is angular momentum conserved in this example? No. Angular momentum is conserved only in the absence of a torque. But a torque indeed exists when the car is changing circles. We can see in the sketch that the sideways track force acts about a lever arm from the center of the circles. This produces a torque that decreases the angular momentum of the car — but not the speed. The car coasts at the same speed with less angular momentum on the inner track. In this case the angular momentum is reduced because the radius is reduced.



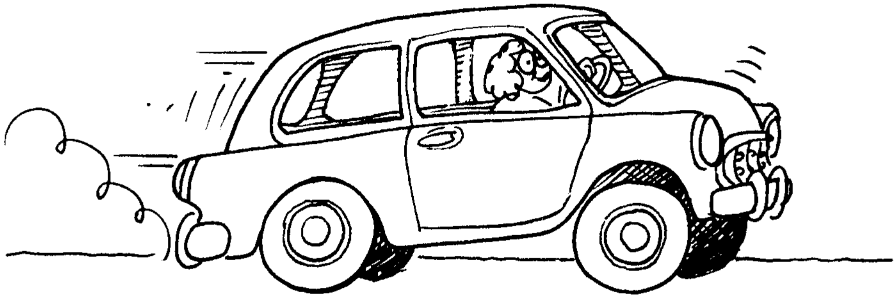
If the car moves in the opposite direction, from the inner to the outer circle, then the torque acts to increase its angular momentum. Angular momentum increases as the radius increases. But as before, the speed of the freely-coasting car remains constant.

We can look at this from a work-energy point of view also: In the case of BALL ON A STRING, the Force Component 1 acted along the direction of the ball's displacement, so work (force × distance) was done on the ball which increased its kinetic energy. (It is important to see that no work is done when the ball moves in a path of constant radius, for then there exists no Component 1). In the case of the car switching tracks no Force Component 1 exists at any point, whether along the circles of constant radius or along the track joining them. The track force is everywhere perpendicular to the displacement and no work is done by the track force on the car. So no change in kinetic energy, or therefore speed, takes place.

NOSING CAR

When a car accelerates forward, it tends to rotate about its center of mass. The car will nose upward

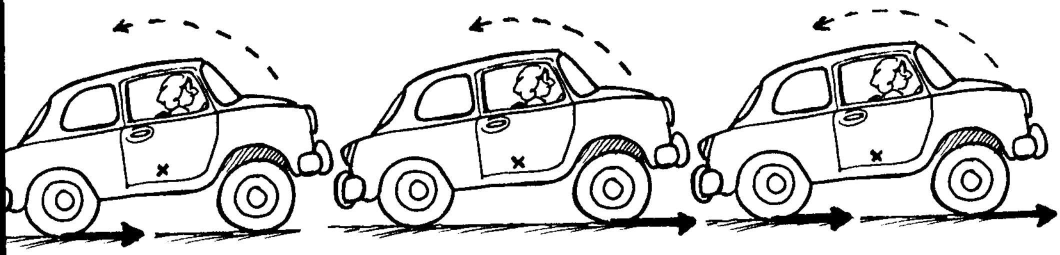
a) when the driving force is imposed by the rear wheels (for front-wheel drive the car would nose downward).
b) whether the driving force is imposed by the rear or the front wheels



ANSWER: NOSING CAR

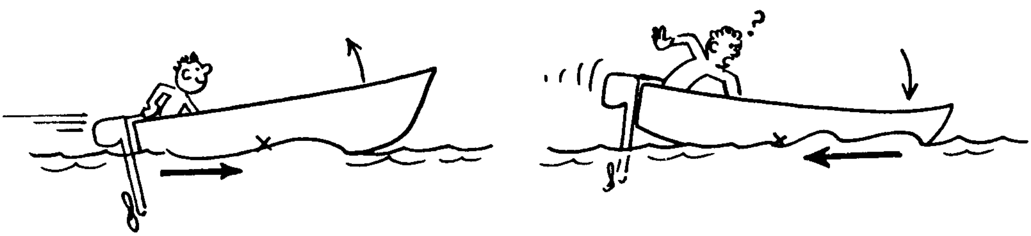
The answer is: b. If the car is accelerated forward, the tires push backward on the road, which in turn pushes forward on the tires. This force of the road on the tires not only accelerates the car forward, but produces a torque about the center of mass of the car. Whether this force is exerted on the rear or front or both sets of wheels, the line of action of the force is along the roadway surface and produces a rotation of the front of the car upward and the back of the car downward (which increases traction for rear-wheel drive vehicles).

We can see from the sketch that in all cases the force of friction (solid arrow) that accelerates the car tends to rotate the car (dotted arrow) counter-clockwise about its center of mass.

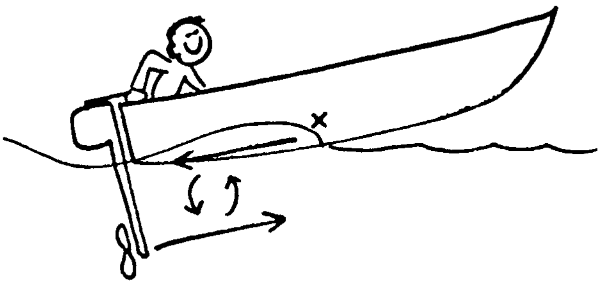


It's easy to see that when the brakes are applied and the force and consequently the torque is oppositely directed, the car noses downward.

This tipping effect is particularly evident in a power boat. Note in the sketch that when the boat accelerates the net force is forward and the torque tips the boat counter-clockwise, but when the boat decelerates and the force of water resistance is predominant, the net force is backward and the torque tips the boat clockwise.



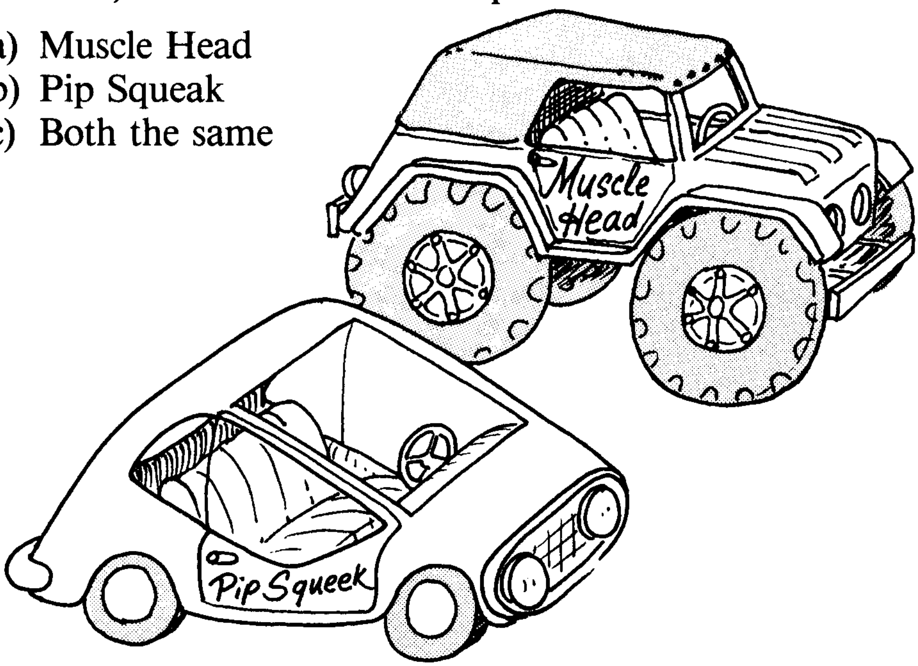
Now a question for the teacher! The car noses up only while it is accelerating and goes back to level once it has achieved a constant speed. But the motor boat stays nosed up. How come? When the boat's speed is constant the friction drag on the hull bottom is equal and opposite to the force on the prop, but the prop is deeper in the drink and is farther than the hull bottom from the boat's center of mass. So the bottom friction and prop act together to produce a turning couple or torque.



MUSCLE HEAD & PIP SQUEAK

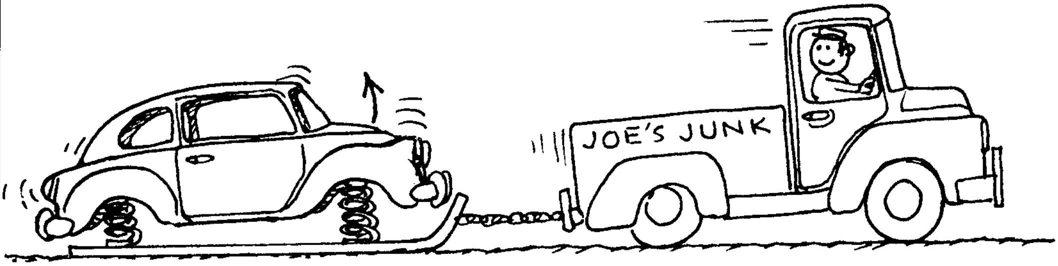
Suppose you had a car that was mostly wheels and another car that had tiny wheels. If the cars have the same total mass and their center-of-masses are equal distances from the ground and each goes from zero to 40 mph in ten seconds, which one will nose up the most?

a) Muscle Head
b) Pip Squeak
c) Both the same



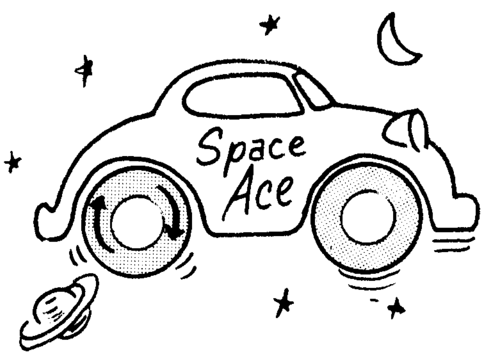
ANSWER: MUSCLE HEAD & PIP SQUEEK

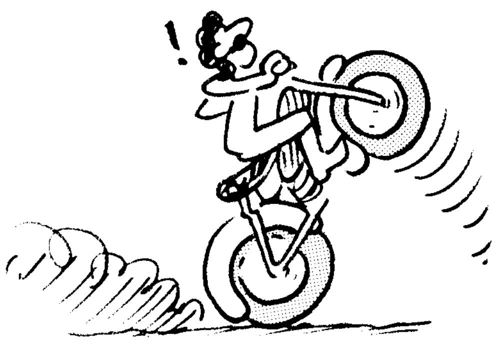
The answer is: a. The wheels did not come into the NOSING CAR story at all — except that they moved the car — so you might expect that the size of the wheels makes no difference here. Even if the car had no wheels and was dragged on a sled it would still nose up when the sled accelerated!



Nevertheless you might have a gut feeling that the big-wheel buggy should nose up the most — and you are right. So far, though, only half of the "nosing" story has been told. To visualize the other half, suppose the car was floating out in intersteller space and you hit the gas and made the wheels spin. What would the car do? Well, it certainly would not go anyplace. Why? Because there is no road to push on — no friction! But it would not just do nothing. If the wheels were made to spin clockwise the rest of the car body would spin anti-clockwise. Why? Because this is the rotational counterpart to action and reaction and momentum conservation.

Now back on earth that effect still operates. There are two effects which make the accelerating car nose up. One depends only on the car's acceleration and has nothing to do with the wheels. The second depends only on the spinning wheels and has nothing to do with the acceleration. If the mass of the wheels is very much less than the mass of the car only the first effect counts for much. But as the mass of the wheels becomes closer to the mass of the vehicle the second effect becomes more important.

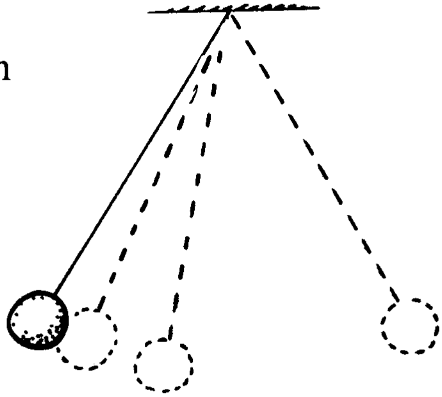




THE SWING

Pull a swing or pendulum to one side, let it go and it will swing back and forth by itself. As it goes back and forth, the swing is conserving

a) angular and linear momentum
b) only angular momentum
c) only linear momentum
d) neither angular momentum
   nor linear momentum



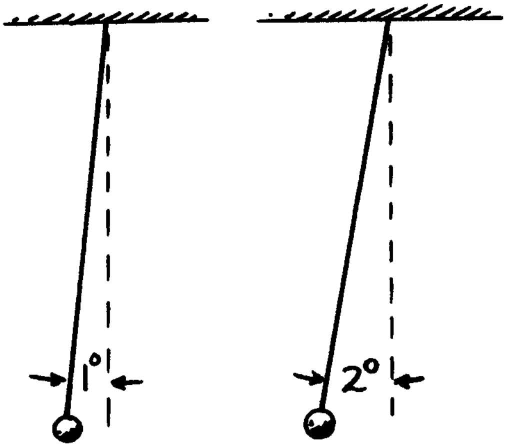
ANSWER: THE SWING

The answer is: d. First the pendulum swings to the right, next it moves back to the left. If the momentum going to the right is $+5$, then when it swings back the momentum must be -5, and when it stops to come back at the end of a swing, the momentum is zero. So the momentum changes from $+5$ to zero to -5 to zero to $+5$ to. . . . It is always changing and so it can't be conserved. What about angular momentum? Well, first it pivots clockwise about the suspension point and at the end of a swing it is momentarily not pivoting at all, and then it pivots counterclockwise, repeating the cycle over and over. So angular momentum is not covserved either. How come? Perhaps you thought momentum was always conserved? Where does the momentum go? When a ball hits a bat where does the momentum go? Into the bat. The linear momentum of the pendulum goes into the string, then into the ceiling, and then into the earth. The angular momentum of the pendulum goes directly into the earth by gravity. That means the earth gets anything the pendulum loses. As the pendulum moves to the right, the earth moves a tiny tiny tiny bit to the left. As the pendulum turns clockwise the whole earth turns a tiny tiny tiny bit anti-clockwise and of course when the pendulum swings the other way the whole earth also reverses its tiny motion. Suppose the earth's mass is a billion times larger than the mass of the pendulum and the pendulum moves one foot to the right. How far does the whole earth move? One billionth part of one foot to the left.

SWING HIGH — SWING LOW

A certain pendulum swings through an arc of one degree in one second. Next, the same pendulum is made to swing through an arc of two degrees. The time required to swing through the two-degree arc is

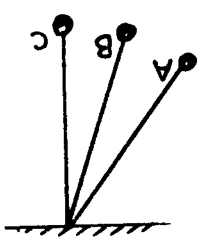
a) one-half second
b) one second
c) two seconds



ANSWER: SWING HIGH — SWING LOW

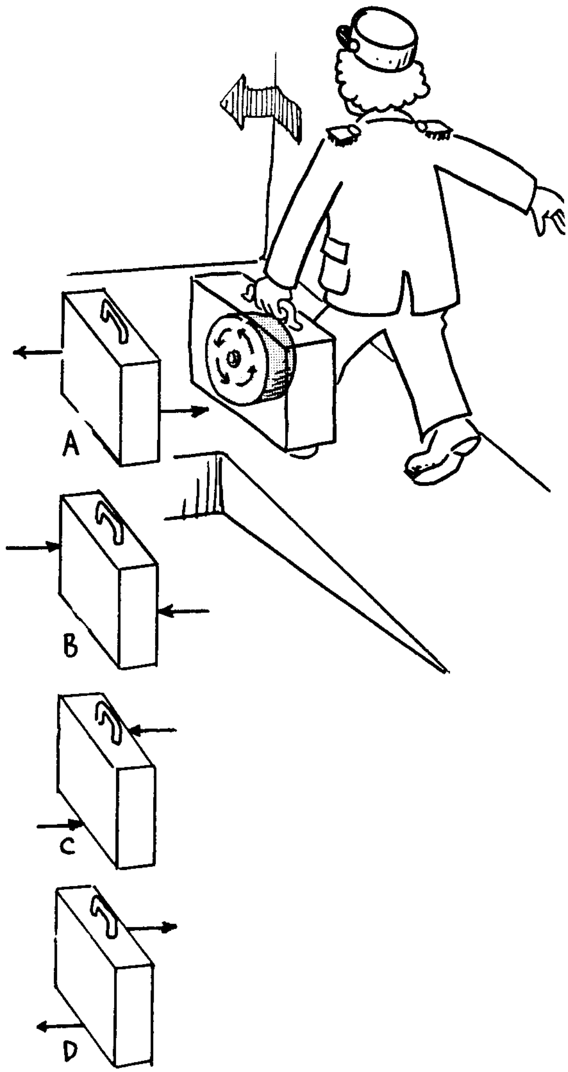
The answer is: ¿. Why not try this one out like Galileo did? Use a long string and a heavy weight. Do not time single swings. Take the time for ten swings. The swings will die a little during the timing, but don't worry about that.

After you do the experiment think about this. Pull the pendulum back to B and let it swing to C. Then pull it to A and let it swing back to C. The trip from A is longer, but faster. It is length of a pendulum, not its displacement, that determines its period of vibration.



GYRO PRANK

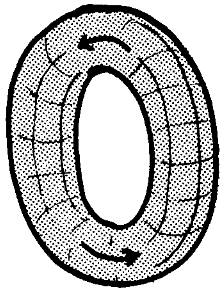
Here's an advanced-level question: An often recounted tale tells of the physicist who hid a large spinning flywheel inside his suitcase. The hotel porter took the suitcase and proceeded to walk around a corner, as shown. What happens to the suitcase?



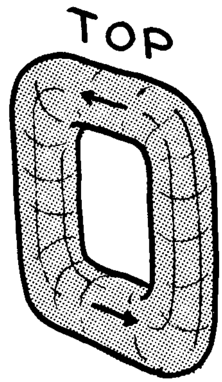
a) The suitcase simply pivoted around the corner in the way the porter wanted it to go, as in sketch A
b) The case tended to pivot in a way exactly opposite to the way the porter wanted it to go, as in sketch B
c) As the porter went around the corner the case pivoted top over bottom, as in sketch C
d) As the porter went around the corner the case pivoted top over bottom, as in sketch D

ANSWER: GYRO PRANK

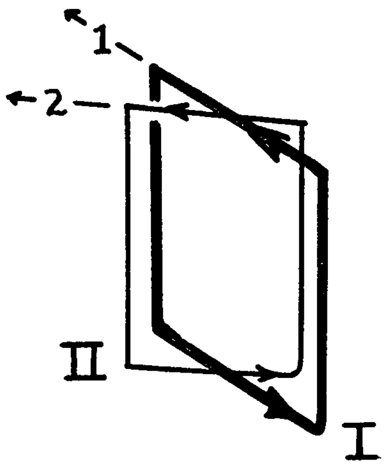
The answer is: d. Gyroscopic motion is quite complicated, but we can simplify it if we picture the spinning flywheel as a round pipe or tire or doughnut in which some heavy liquid is circulating. Next, picture the ring made into a square ring. The liquid circulates by flowing up one side, then horizontally over the top, then vertically down the other side and then horizontally back on the bottom.



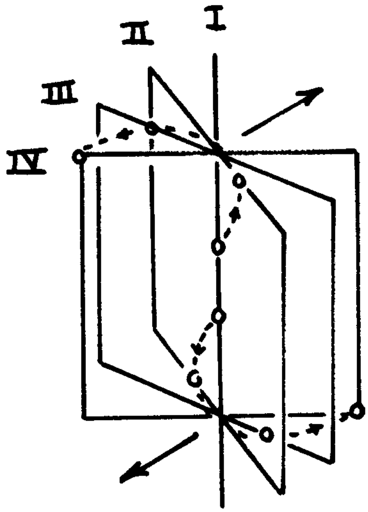
Next, picture the "square" flywheel pivoting from position I to position II as the porter goes around the corner. The part of the liquid flowing up and down in the vertical arms of the pipe does not change its direction of flow as the square flywheel or loop pivots from position I to II — the vertical sides remain vertical. But the liquid flowing in the horizontal arms does change its direction of flow. For example, the liquid in the top might begin flowing in direction 1 and finish in direction 2.



The last sketch shows how a portion of liquid flowing in the top pipe or bottom pipe is actually forced to travel in a curve as the porter turns the loop. Now, when a thing goes through a pipe which is turning it exerts a force on the side of the pipe. (Remember CAROUSEL.) Why? Because the thing tends to go straight, but is forced to turn. The arrows in the last sketch show the direction of the force on the sides of the pipe. The curves on the top and bottom are opposite and so the direction of the



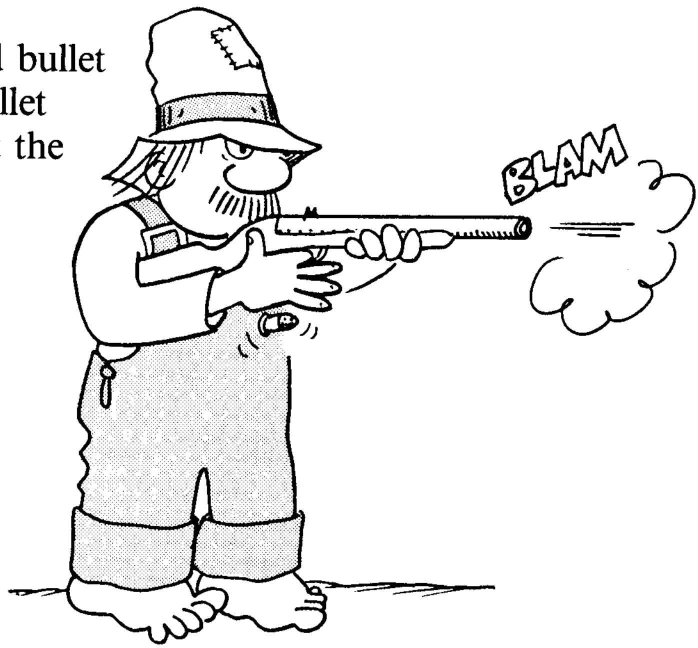
force on the top and bottom are opposite. The force on the pipe is the same as the force on the flywheel and that force is communicated to the suitcase. The top tilts to the right and the bottom to the left — as in sketch "D."



THE DROPPING BULLET

At the same time that a high-speed bullet is fired horizontally from a rifle, another bullet is simply dropped from the same height. Which bullet strikes the ground first?

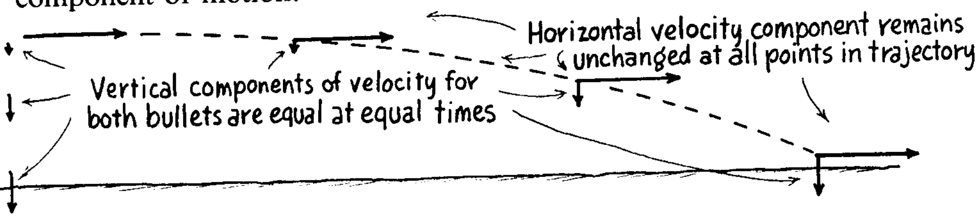
a) The dropped bullet
b) The fired bullet
c) Both stike at the same time



ANSWER: THE DROPPING BULLET

The answer is: c. This is because both bullets fall the same vertical distance with the same downward acceleration. They therefore strike the ground at the same time (gravity does not take a holiday on moving objects).

This problem can be better understood by resolving the motion of the fired bullet into two parts; a horizontal component that doesn't change because no horizontal force acts on it (except for air resistance), and a vertical component that accelerates at *g* and is independent of its horizontal component of motion.

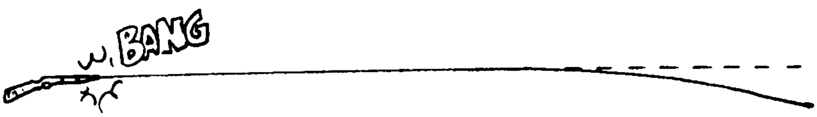


Or we can look at this another way. If the rifle is pointed upward above the horizontal then the dropped bullet will strike the ground first. If on the other hand, the rifle is pointed downward toward the ground, the fired bullet obviously wins. Somewhere between up and down, there will be a draw — and that's when the rifle is horizontal.

And there's another and quite different way to look at this: Suppose the ground accelerated upward, rather than the bullets downward. Can you see that the outcome would be the same?

FLAT TRAJECTORY

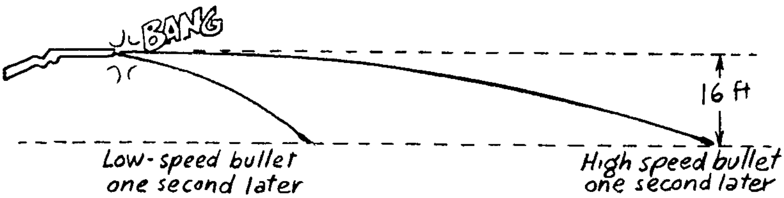
A bullet shot from a very high velocity rifle may travel one hundred feet or more without dropping at all.



a) True
b) False

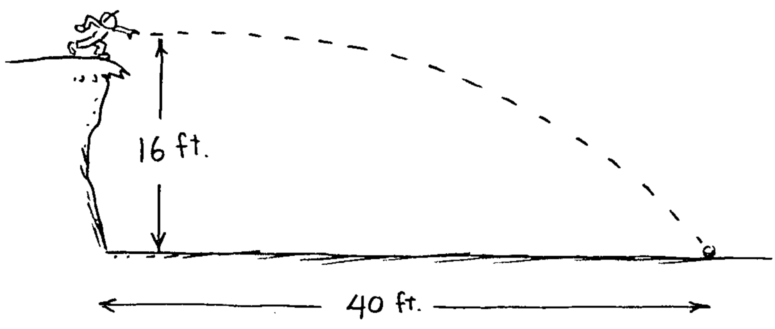
ANSWER: FLAT TRAJECTORY

The answer is: b. There is a popular idea around, even taught in some police academies, that a sufficiently high-powered bullet will go some distance without dropping at all. But this is a real misconception. The speed of a thing cannot "turn off" gravity, not even for a moment. Even light from a laser begins to drop the moment it begins its flight. Moreover, the rate of drop is always the same, regardless of speed. If the bullet is fired horizontally in a so-called "flat trajectory," it falls 16 feet during the first second of flight. However, during that second a high speed bullet will go farther than a low speed bullet so the flight path or trajectory of the high speed bullet looks less curved than the trajectory of the low speed bullet, but both always curve. A trajectory can never be completely flat (unless it is straight up or straight down).



PITCHING SPEED

A boy throws a rock horizontally from an elevated position 16 feet above the ground as shown. The rock travels a horizontal distance of 40 feet. How fast did the boy throw the rock? (Again, consider time.)



a) 16 ft/s
b) 40 ft/s
c) 43 ft/s
d) 56 ft/s
e) Cannot be solved with the information given

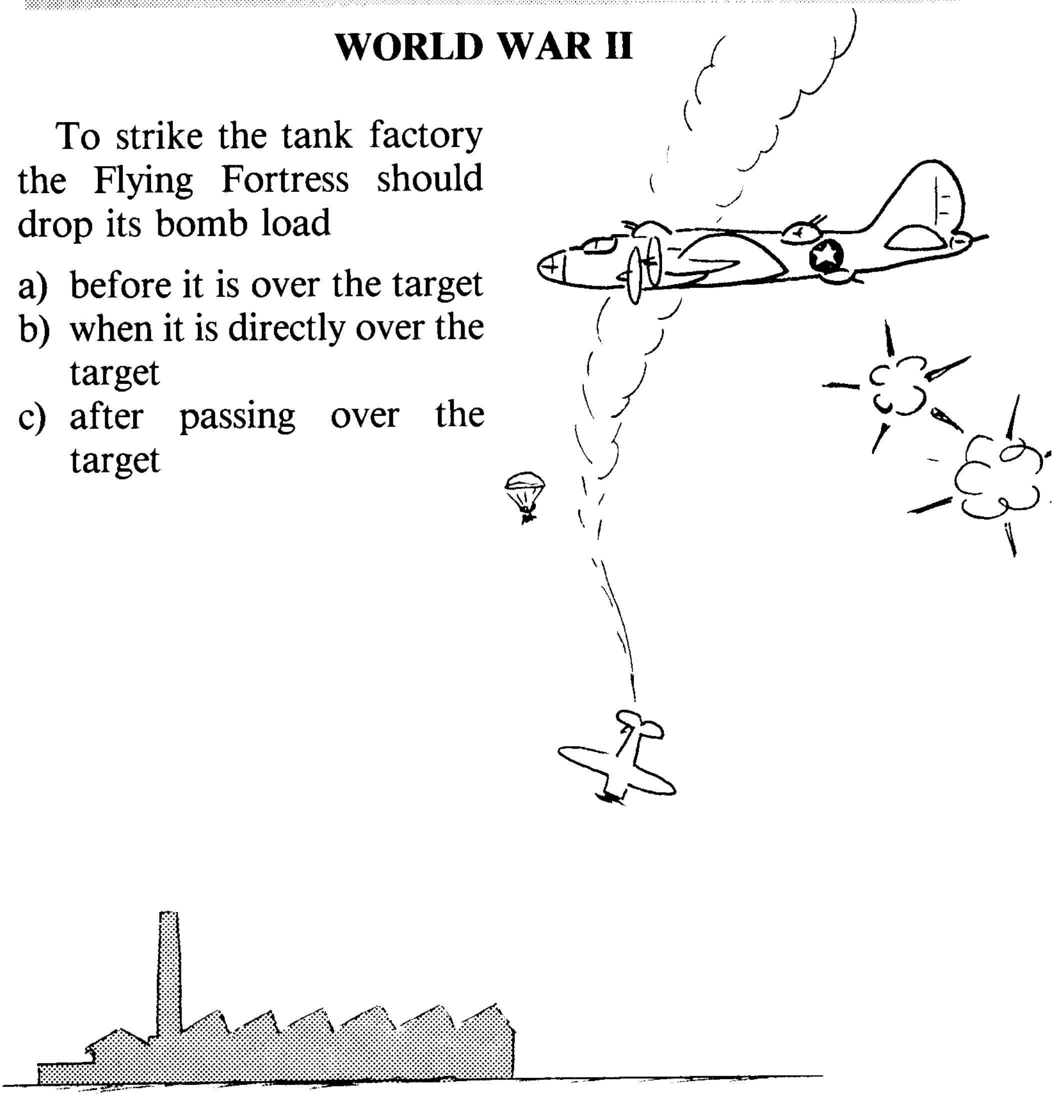
ANSWER: PITCHING SPEED

The answer is: b. We know that speed $= \dfrac{\text{distance traveled}}{\text{time taken}}$, and we are given that the rock travels 40 feet. Since the rock was thrown exactly horizontally with no initial component of velocity in the up or down direction, the time taken is the same time that would be required for the rock to fall 16 feet if it were simply dropped from rest. This time is one second, so the stone's horizontal velocity must be 40 ft/s.

WORLD WAR II

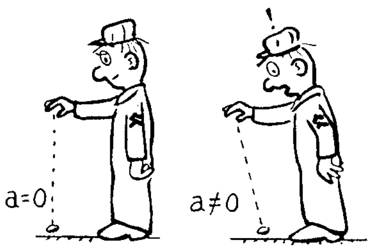
To strike the tank factory the Flying Fortress should drop its bomb load

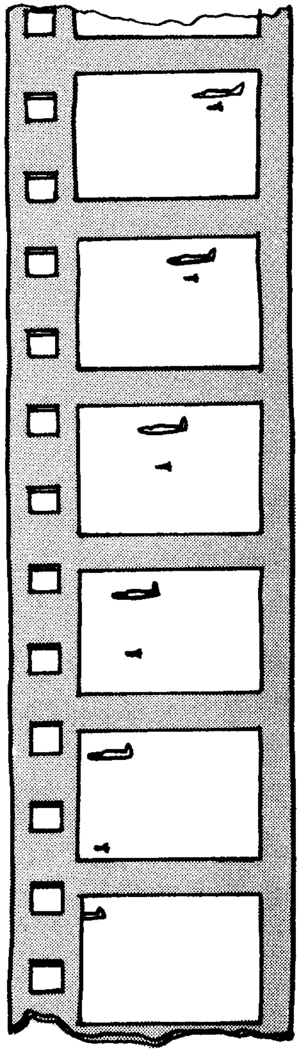
a) before it is over the target
b) when it is directly over the target
c) after passing over the target



ANSWER: WORLD WAR II

The answer is: a. When the bomb is dropped it does not simply fall vertically to the ground straight below — such motion would require a zero horizontal velocity. When the bomb is released it has an initial horizontal component of velocity equal to that of the Flying Fortress (B29). If air resistance is negligible the dropping bomb continues forward with the airplane's velocity. The film shows how the bomb trails along directly under the aircraft. The bomb actually trails behind somewhat because air resistance is not really negligible. But if you drop a coin while inside the moving plane, then air resistance is negligible and the coin will fall at your feet. This is because its forward component of velocity is the same as that of your hand and your feet. It keeps up with the moving airplane. But if the plane accelerates while the coin is dropping, the coin does not land directly below its dropping position. Why?



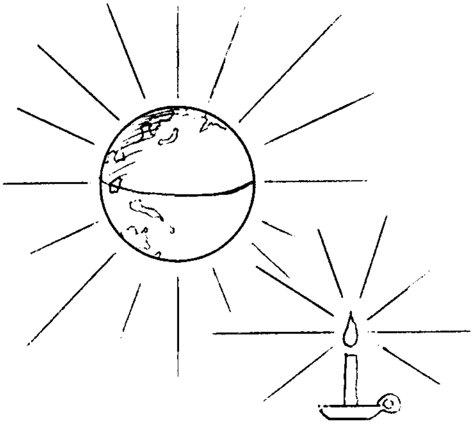


BEYOND THE REACH

Is it possible to get beyond the earth's gravitational field if you go far enough away from the earth?

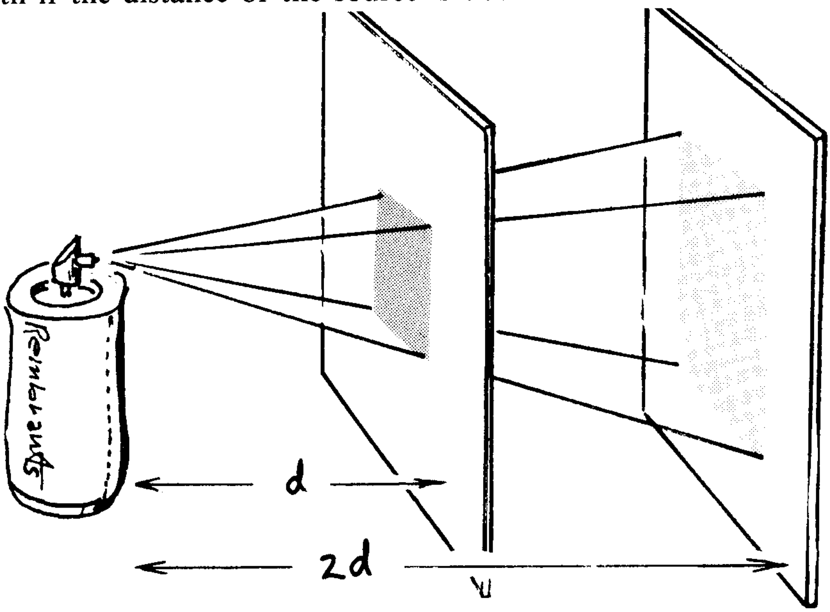
a) Yes, you can get beyond the reach of the earth's gravity
b) No, you cannot get beyond the reach of the earth's gravity

ANSWER: BEYOND THE REACH



The answer is: b. Newton's vision of gravity is that "lines of flux" or "tentacles" reach out from the earth (or from any mass) into space. The lines of flux NEVER END. They go on forever. But, as they reach further and further into space they get more and more spread out so the force of gravity, which they produce, gets weaker and weaker but never disappears completely. it is like the light rays which come out from a candle, or radiation particles emanating from a piece of radioactive ore. They spread into space. The radiation gets weaker and weaker, but the rays go on forever.

How much weaker? That depends on distance. Visualize a paint spraying can. The can sprays a little square on the wall. Now suppose the wall is twice as far from the can. How much lighter or thinner is the paint spray on the more distant wall? That depends on how much more area the same spray must cover. How much larger is the area of the second square? Twice as large? No. The second square is twice as high and twice as wide, so its area goes up *four* times. So the spray is only one fourth as dense in the second square. Likewise, the intensity of gravity, or heat, sound, or light from any such point-like source is reduced to one fourth if the distance of the source is doubled. If the distance of the

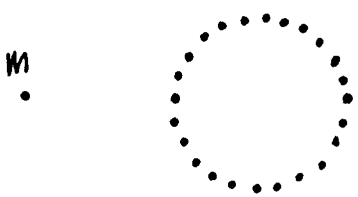


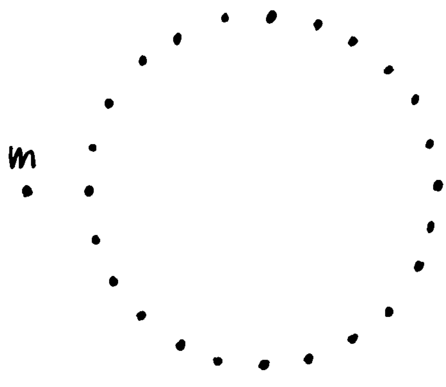
source is increased three times, the square is three times higher and wider, so spray density is reduced nine times. In general, for any stuff spreading through space from a point source: Intensity$\sim 1/(\text{distance})^2$. This results in a very sudden rise in intensity as you get close to the source. Thus, children get the notion that heat is "in" a flame and that the surrounding space is cold.

Back to gravity. Surrounding every bit of matter in the universe is a gravity field. You are matter, and you are surrounded by your own gravity field. How far does it reach? To the far ends of the universe. Your influence is everywhere. . . really!

NEWTON'S ENIGMA

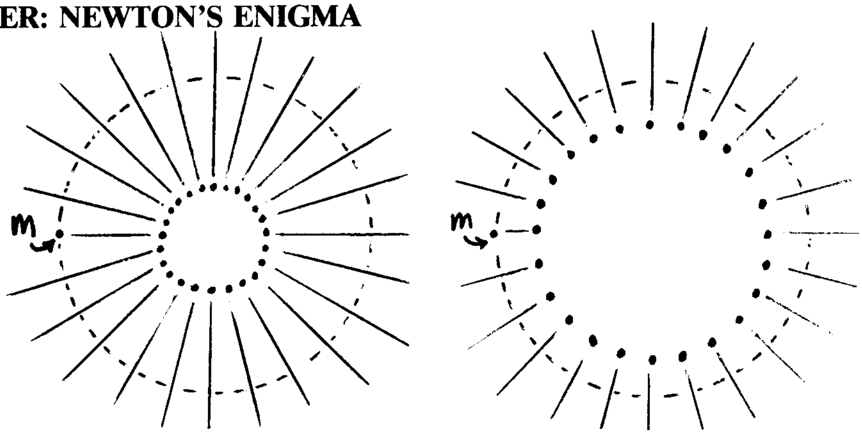
This question troubled Newton for many years. A little mass, "m," is a certain distance from the center of a globular cluster of masses and there is a certain force of gravity, due to the cluster of masses, on the little mass that pulls it toward the center of the cluster. Now consider the situation whereby neither the little mass nor the center of the cluster moves, but the cluster uniformly expands. As a result of this expansion some parts of the globular cluster are closer to "m" and some are farther from "m." After the expansion, the forces of gravity of the cluster on the little mass "m" will





a) increase
b) decrease
c) remain unchanged

ANSWER: NEWTON'S ENIGMA



The answer is: c. To see why, picture the gravity field reaching out from the globular cluster like the tentacles of an octopus, one force tentacle from each mass in the cluster. The force of the field depends on how close together the tentacles are. Physicists call the tentacles "lines of flux" or "flux lines." Up close to the globular cluster the lines are close together and the force is strong. Further away they are spread apart and the force gets weaker.

Now picture a spherical bubble around the cluster. As long as the cluster stays inside the bubble, the number of flux lines going through the surface of the bubble will not change. So the strength of the gravity field at the bubble's surface does not change.

So the force on "m," which is at some point on the bubble, does not change. Of course, this bubble is just an imaginary thing.

If the globular cluster of mass is hollow, the sketch makes it look like there is no gravity inside the hollow, and in fact, there is no gravity in a hollow globe, at least no gravity due to the mass of the globe.

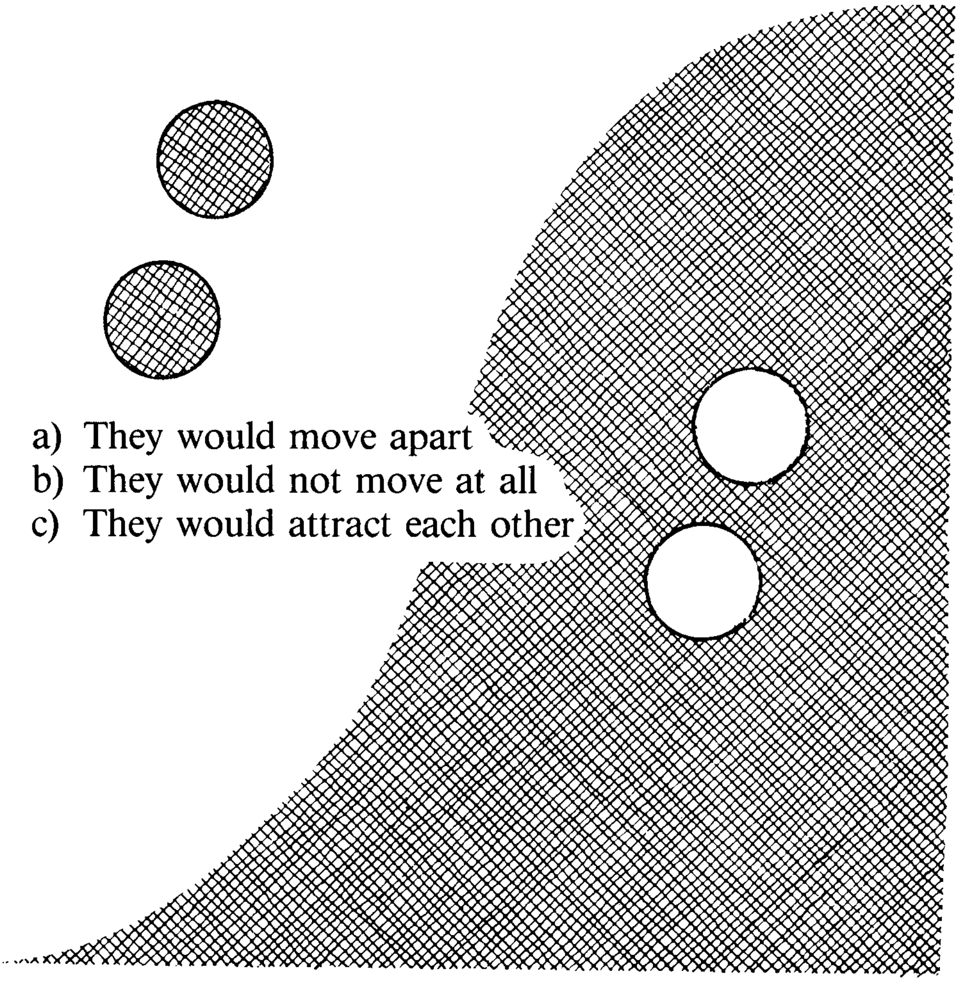
Why was Newton thinking about this? Because he pictured the earth itself as a globular cluster of little masses or atoms (but not a hollow globe). He wanted to show that the force field outside the globe was the same as the force field which would exist if all the mass in the globe was compressed to the globe's center. It makes calculations so much easier when you can think of all the mass being at one point rather than being spread all over in the cluster.

Incidentally, Newton eventually figured out the answer was "c," but he did not picture the bubble. The bubble idea came from a mathematician named Karl Friedrich Gauss, who just might have been the smartest person who ever lived. Needless to say, Gauss figured out a lot of things besides the bubble. Gauss lived during the time of Napoleon and Beethoven, which was after Newton's time.

TWO BUBBLES

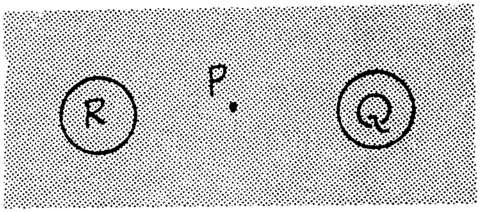
This is a rather advanced problem, so either skim it or dig in!

If all space were empty except for two nearby masses, say two drops of water, the drops would, according to Newton's Law of Gravity, be attracted together. Now suppose all space were full of water except for two bubbles. How would the bubbles move?

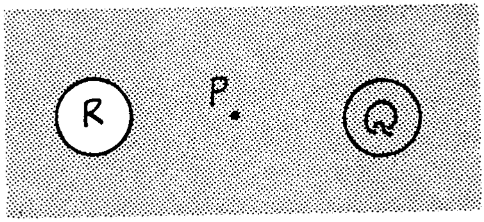


a) They would move apart
b) They would not move at all
c) They would attract each other

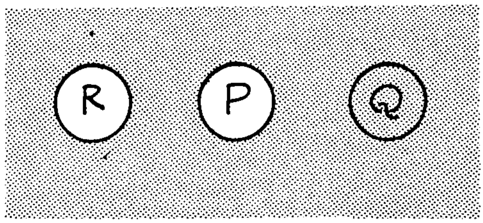
ANSWER: TWO BUBBLES



The answer is: c. What is the point of this question? There are at least two points. The first is to show how easily a simple situation, which we think we thoroughly understand, can be transformed (by turning it inside out) into a baffling situation. The second point will come later.



Why do the bubbles move together? If all space were completely full of water there would be no net gravity at point **P** because any attraction due to water at **Q** would be cancelled by the attraction of the water at **R**. But if the water at **R** is removed to make a bubble, the balance at **P** is upset and there is a net attraction to the water at **Q**. So now there is gravity at **P** — the attraction is towards **Q** or away from **R**. It is as if **R** repelled things.



But what is meant by "things"? By things we mean particles, pebbles, and rocks and the like. A rock at **P** would move away from **R**. But what about bubbles? How does gravity affect bubbles? Gravity makes rocks and bubbles move in opposite directions — rocks down, bubbles up. So if a rock at **P** would move away from **R** then another bubble at **P** would move towards **R**. The bubbles would attract each other.

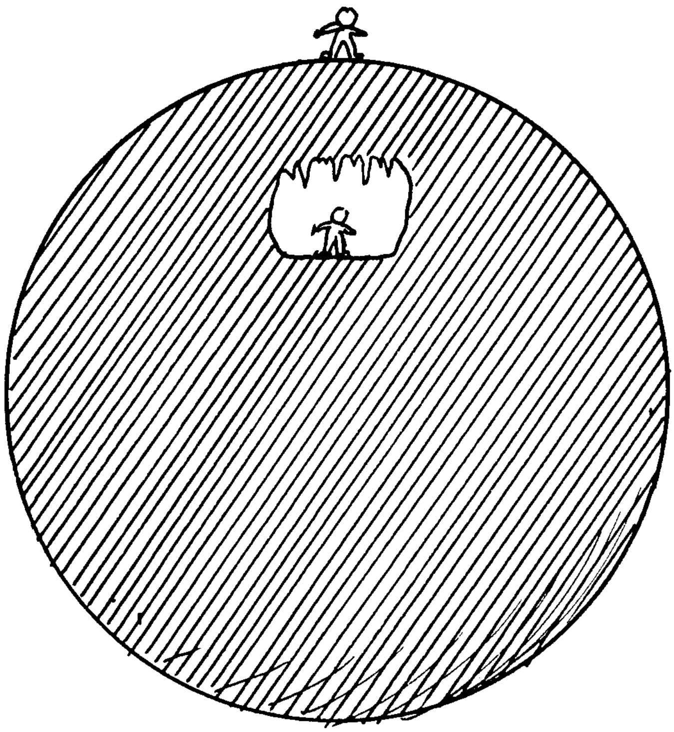
Now for the second promised point of this question. We started with the idea that mass attracts mass and from that reasoned that bubble must attract bubble or empty space attracts empty space. But we could have just as well started with the idea that empty space attracts empty space and from that reasoned that mass must attract mass. Our universe is mostly empty space with a little mass in it so we get one view of things, but if our universe were mostly mass with a little empty space in it we would get a different view of things. Or, on the other hand, we might just interchange our idea of what was mass and what was empty space.

In physics you are always close to the deep water. Take two steps off the beaten path and you may be into it. And it's not make believe.

INNER SPACE

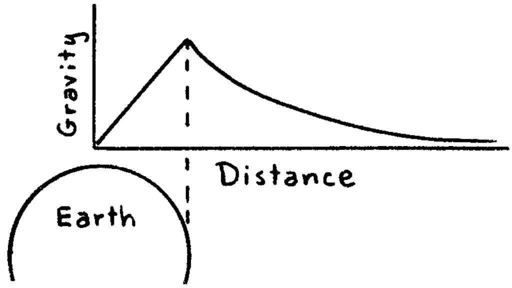
Down in a cave below the surface of the earth there is

a) more gravity than at the earth's surface
b) less gravity than at the earth's surface
c) the same gravity as at the surface



Assume that the earth's density is the same all the way through. Of course it isn't. But simplistic idealized situations must be thoroughly understood before details can be appreciated.

ANSWER: INNER SPACE



The answer is: b. There is less gravity in the cave because some of the earth's mass is above your head when you are in the cave and that mass pulls up on you and so cancels the effect of some of the mass below your feet which pulls down on you. What if the cave were at the very center of the earth? In that case there would be no gravity at all in the cave. It would be just like floating in "zero g" in a spaceship! Why? Because there would be equal amounts of earth "above" and "below" you.

Things on the surface of the earth, where we live, experience the most gravity. If you go up from the surface away from the earth into space, gravity gets weaker and if you go down inside the earth it also gets weaker.

FROM EARTH TO MOON

Of the five places listed below it would be easiest to launch a spacecraft from the earth from

a) New Mexico (south over Mexico)
b) California (north over the Pacific Ocean)
c) Florida (east over the Atlantic Ocean)
d) Moscow (east over Siberia)

The first trip to the moon was, in fact, launched from (see above)

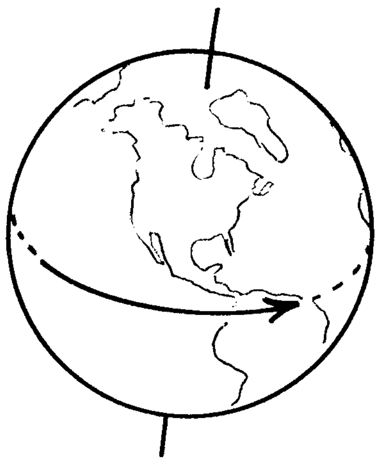
a) b) c) d) e)

A century ago Jules Verne thought the journey to the moon would commence from (see above)

a) b) c) d) e)

ANSWER: FROM EARTH TO MOON

The answer is: c. The earth spins from west to east, which is why the sun rises in the east and sets in the west. (Stop and visualize that.) So if you launch the spacecraft to the east you can use some of the earth's spin "for free." Since the earth spins around its pole, the pole stands still, and those parts of the earth near the pole move slowly; those parts farther away move fastest. The equator is farthest away from the poles and moves fastest. Therefore the best way to launch is to the east from the equator — or as close to it as you can get.



The answer to the second and third questions is also: c. It is history now.

EARTH SET

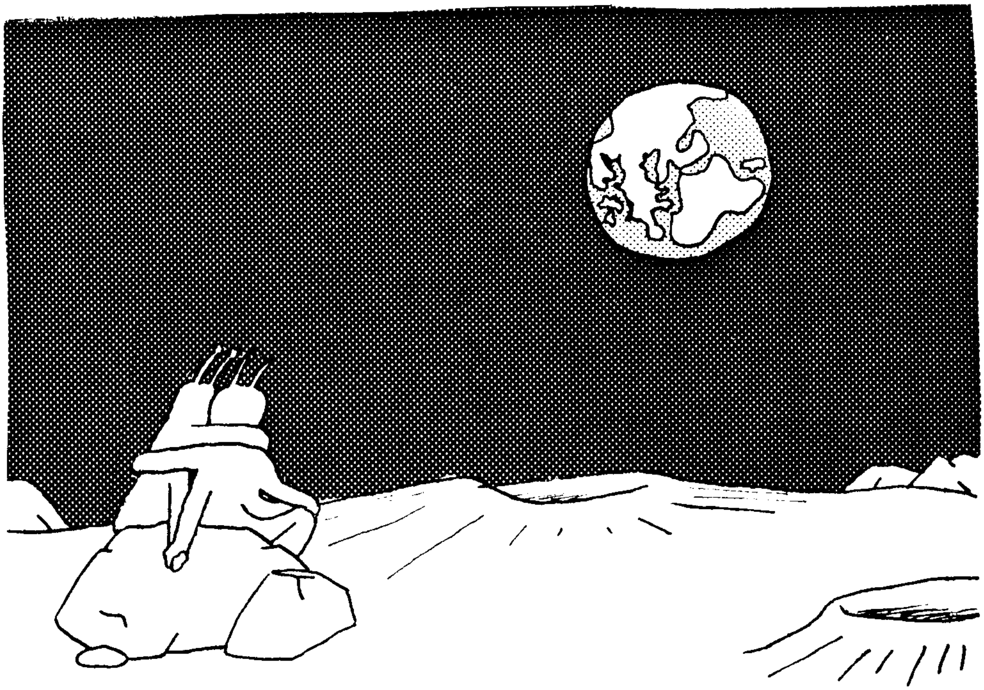
Suppose you lived on the moon. Suppose the earth was directly over your head. How long would it be before you would see the earth set?

a) one day (one earth day, 24 hours)
b) one-fourth of a day (6 hours)
c) one month (the time it takes the moon to orbit the earth
d) one-fourth of a month
e) you would never see the earth set

ANSWER: EARTH SET

The answer is: e. As seen from earth you always see one side of the moon. That's why the ancient astronomers thought the moon was something stuck on the dome of the sky, rather than another world. The back of the moon was a subject of mystery until first photographed by a Russian spacecraft.

If you lived on the side of the moon that faced the earth you would never see the earth set because that side of the moon continually faces the earth.



PERMANENT NIGHT

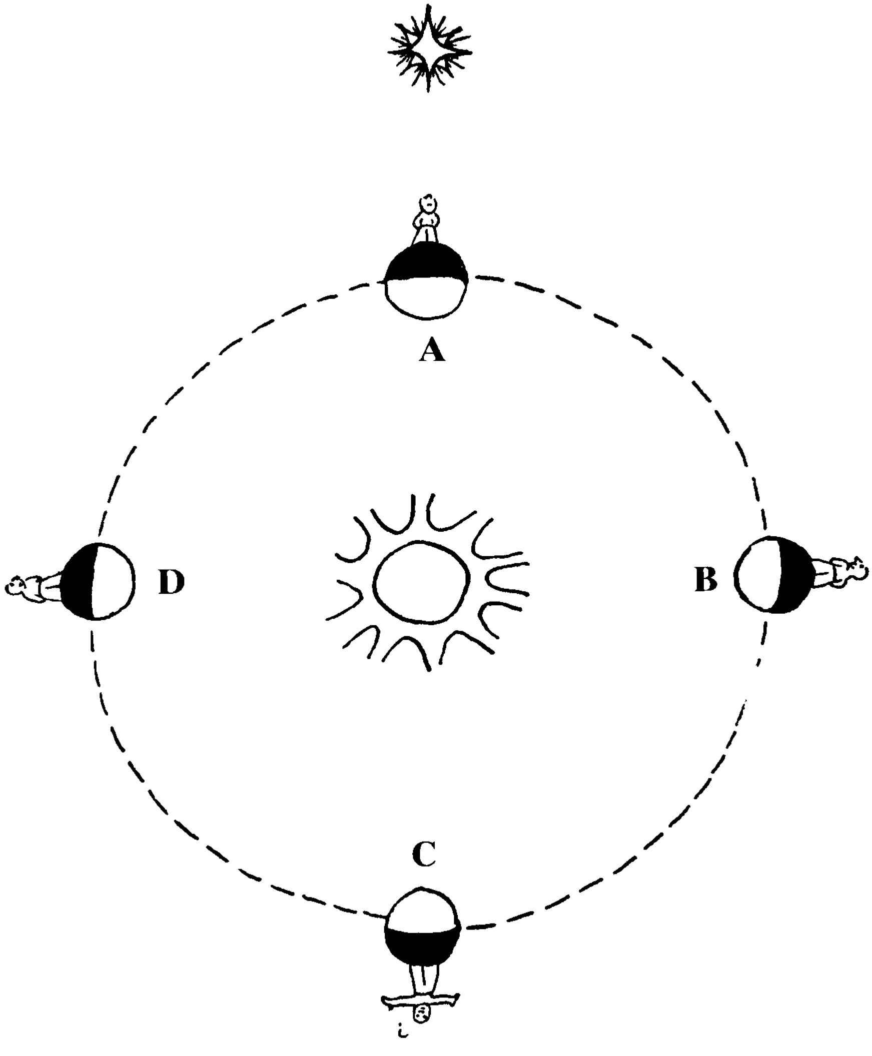
Suppose the earth still goes around the sun every year but you keep one side of the earth always facing the sun, so one side always sees the sun and the other side never sees it. As seen from the earth, the sun is stationary in the sky. Now in this supposed situation the stars would

a) also seem stationary in the sky
b) would seem to go once around the earth every day
c) would seem to go once around the earth every year

ANSWER: PERMANENT NIGHT

The answer is: c. As seen by someone standing in the middle of the dark side of the earth, the star is overhead when the earth is at position **A**. The star is underfoot one-half year later when the earth is at **C** and back overhead again one year later when the earth gets back to **A**. So even though the sun is frozen in the sky, causing one side of the earth to have a permanent day and the other side a permanent night, the stars would still seem to go around the sky once every year.

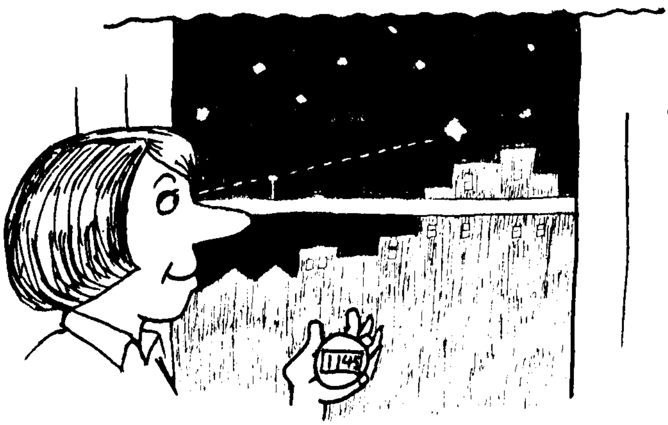
Thank God this is not now the existing situation, though there is reason to believe that some time in the distant future (when the earth's spin is reduced by tidal friction) this will become the existing situation.



STAR SET

Using a good digital watch, get the exact time when a bright star goes behind a distant building or tower. A day later time the disappearance again. Sighting over a nail fixed in a window sash will help you return your eye to the same location for each sighting. It will be found that

a) the star disappears at the same time each night
b) the star disappears a little earlier each night
c) the star disappears a little later each night



ANSWER: STAR SET

The answer is: b. The motion of the stars in the night sky is due to the earth spinning, so the stars, like the sun, should seem to go around the earth every twenty-four hours, but not quite. Why not quite? Because you have two circular motions: one around the earth every day and one around the sun every year.

If the earth kept one side facing the sun all the time the star would go around the earth once every year. But the earth does not keep one side facing the sun. It spins around so one side does not always face the sun. It spins so fast that you see the sun go around about 365 times each year. So you also see the star go around 365 times each year. NO. You see the star go around 366 times! Why the extra time? *Because it would go around once each year even if the earth kept one side always facing the sun.* Remember, there are two circular motions, and the total circular motion is the sum of both.

How do you know the circular motions should be added together? Maybe one should be subtracted from the other. The two motions add because the earth's daily spin and yearly orbit both circle the same way. The sun also spins the same way. The earth's spin and orbital motion probably came with the material taken from the sun when the earth was created. That's why all circle the same way.

So the star must go around the sky a little faster than the sun. The sun goes around once in about 24 hours so the star goes around once in a little less than 24 hours. How much less? The sun goes around the sky in about 1,440 minutes (1,440 minutes = 24 hours × 60 minutes per hour). The star must go around the sky a bit faster so that after one year it has made it around one more time than the sun. In other words the star has to get in an extra turn in one year. If a normal turn (sun turn) takes 1,440 minutes and if you cut that time by 4 minutes (4 times 365 approximately equals 1,440) then after 365 turns (one year) you will be one turn ahead.

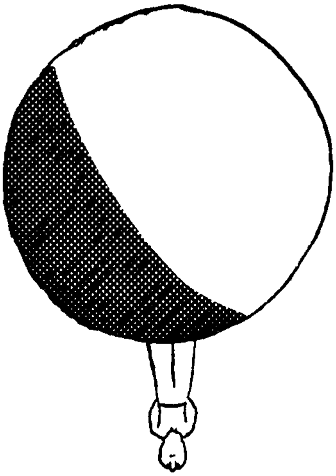
So stars don't set (or rise) at the same time each night. Each night they come up (and go down) four minutes earlier than they did the night before. That adds up to roughly half an hour in a week. So at the same time of night you don't always see the same stars in the sky, even though at the same time of day (say noon) you always see the same star—the sun. It is this effect that causes the constellations in the winter night to be different from those in the summer night.

In 1931 a radio engineer named Jansky who worked for the Bell Telephone Labs picked up radio noise on a particularly sensitive short wave receiver at about the same time each day. No one could tell or even guess where the radio noise came from. Then Jansky noted that the noise came four minutes earlier each day. He said that means the radio noise must be coming from the stars. For years no one would believe it, but he had in fact discovered the first extraterrestrial radio source—the center of the Milky Way.

LATITUDE AND LONGITUDE

By glancing at the night sky you can immediately estimate your

a) latitude
b) longitude
c) both
d) neither



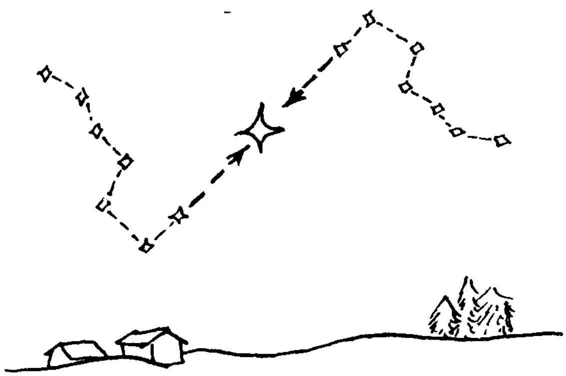
ANSWER: LATITUDE AND LONGITUDE

The answer is: a. If the North Star is directly over your head you must be at the north pole. (If it is directly under your feet you must be at the south pole.) If it is halfway between overhead and underfoot—that means on the horizon—you are at the equator. If the North Star is halfway between overhead and the horizon—that means 45° up from the horizon (or down from the zenith)—you must be at 45° north latitude. Why not 45° south? Because at 45° south you could not see the North Star.

Is the North Star the brightest star in the sky? No. But it is easy to find—see the sketch. The Big Dipper points the way. I have drawn two Big Dippers because the Dipper spins around the North Star every day, so sometimes it will be above the star and sometimes below it and sometimes to the right or left of it. The North Star is about as bright as a Dipper star.

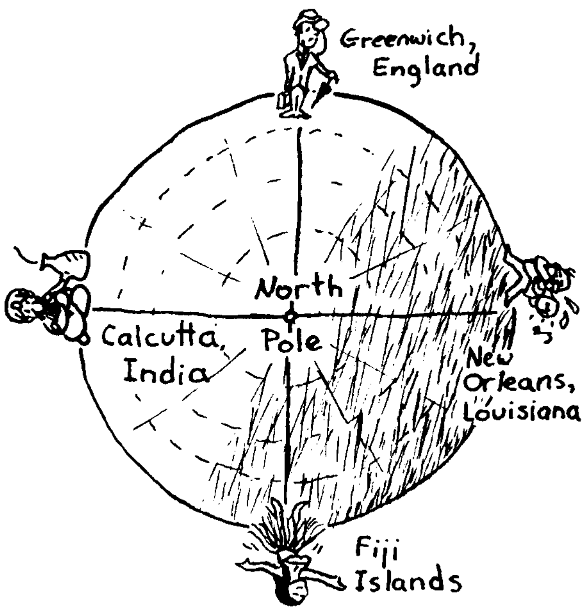
What about longitude? What is longitude? Longitude is how many degrees you are east or west of Greenwich, England. The Fiji Islands and Greenwich are on opposite sides of the earth so the Fiji Islands are at 180° east or west longitude (it doesn't matter when you go halfway around).

New Orleans, Louisiana, is west of England a quarter of the way around the world and so at 90° west longitude. Calcutta, India, is a quarter of the way around the world east of England and so at 90° east longitude.



How can you tell what your longitude is? By looking at the stars? That won't work because the sky over New Orleans at midnight tonight (New Orleans time) will be identical to the sky over Cairo, Egypt, at midnight tonight (Cairo time). You need more than a look at the sky. You need to know the time.

You need to know not only the local time, which you can tell by looking at a sundial, you also need to know what time it is in Greenwich, England. How does it work? Well, suppose it is noon where you are and you get on the telephone and ask Greenwich what time they have. Greenwich answers "midnight." Where are you? On the side of the earth opposite Greenwich, 180° east or west longitude. Before telephones and radios sailors had to carry



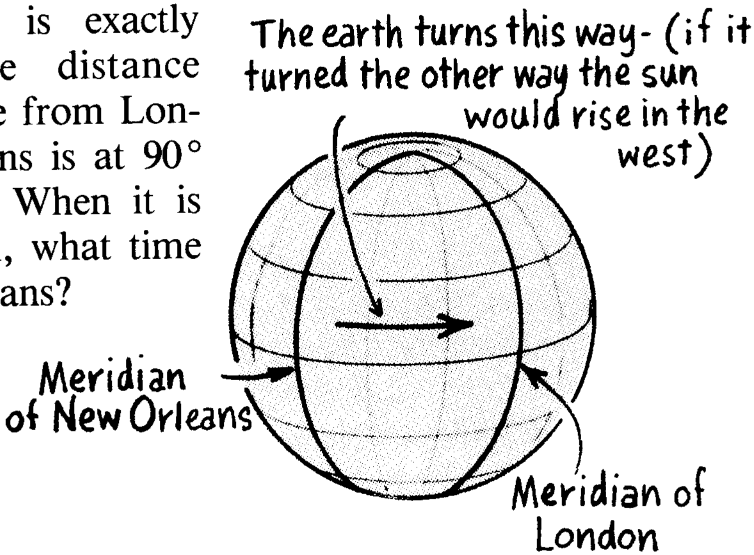
clocks reading Greenwich time. If the sailors' clock was only one minute slow or fast the ship's navigation could be 16 miles in error (16 miles = 24,000 miles around the world divided by 1,440 minutes around the day).

Why is it so much more difficult to tell longitude than latitude? Because latitude was made by God; longitude is man-made. That is, Nature designated the north pole by the way of the earth spins, but people designated Greenwich. According to some people, longitude should not even be measured from Greenwich. According to the metric system the earth should be divided into one thousand metric degrees (not 360°) starting from Paris, France. On some homestead and U.S. land grant documents longitude is designated from Washington, D.C.

A SINGULARITY

New Orleans is exactly one-quarter the distance around the globe from London (New Orleans is at 90° west longitude). When it is noon in London, what time is it in New Orleans?

a) Noon
b) Midnight
c) 6 a.m.
d) 6 p.m.
e) anytime



When it is noon in London, what time is it at the North Pole?

a) Noon b) Midnight c) 6 a.m. d) 6 p.m.
e) anytime

ANSWER: A SINGULARITY

The answer to the first question is: c. One-quarter of 24 hours is 6 hours. The sun is now high over London. In six hours the earth will turn New Orleans under the sun. So, it must be 6 AM in New Orleans.

The answer to the second question is: e. It is noon at any place on earth when the sun is over the meridian running through that place, but all meridians run through the North Pole, therefore the rule for telling time breaks down at the North Pole.

A place where a rule breaks down is called a singularity. Usually the rules that break down are rules for calculating something. (For example, what is $\frac{1}{x-2}$ when x equals 2? Infinity? Plus infinity or minus infinity?) There is the fantastic possibility that there are singularities in the universe where the laws of physics break down, as for example, at the center of a black hole.

PRESIDENT EISENHOWER'S QUESTION

Almost everyone in the U.S.A. was astonished and concerned when the U.S.S.R. won the first round of the space race by launching the first earth satellite, SPUTNIK, in 1957. The most vital question was the mass of the payload (spacecraft) which the U.S.S.R. could orbit. This was the question the President of the United States asked his science advisors: "All we know for certain about Sputnik is its altitude and orbital speed. From that information can you calculate Sputnik's mass?" The science advisors answered:

a) "Yes, we can."
b) "No, we cannot."

ANSWER: PRESIDENT EISENHOWER'S QUESTION

The answer is b. Just as rocks of different masses falling without air resistance fall identically (recall FALLING ROCKS), and just as projectiles of various masses thrown with equal velocities follow identical trajectories, satellites of whatever mass moving at equal velocities at equal altitudes fall around the earth in the same orbit. The force that holds a satellite in orbit is simply the weight of the object at that altitude which in turn is proportional to its mass. So if the mass of a satellite should be doubled, the force holding it in orbit is also doubled — it would have twice the weight. Sputnik would stay in the same orbit at the same speed whatever its mass.

Only by actually probing Sputnik could we determine its mass. For example, if it were probed with another satellite of known mass and velocity, and the velocity of rebound measured, then the mass of Sputnik could be determined by momentum conservation. But without interacting with it, its mass cannot be determined by means of the orbit it follows.

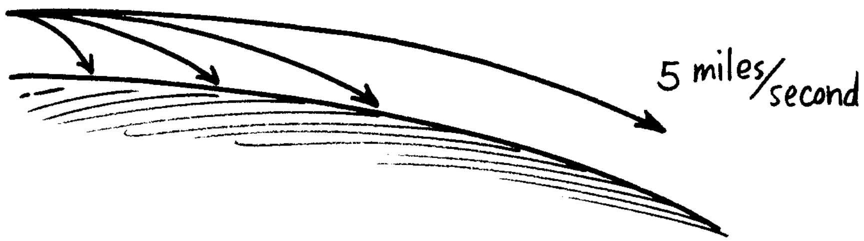
TREETOP ORBIT

If the earth had no air (atmosphere) or mountains to interfere, could a satellite given adequate initial velocity orbit arbitrarily close to the earth's surface — provided it did not touch?

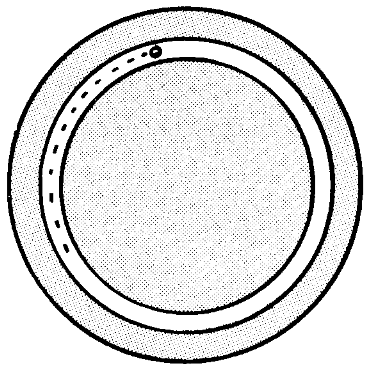
a) Yes, it could
b) No, orbits are only possible at a sufficient distance above the earth's surface where gravitation is reduced

ANSWER: TREETOP ORBIT

The answer is: a. It is important to realize that a satellite is simply a freely falling body that has enough tangential or sideways speed to enable it to fall around the earth rather than into it. If a projectile is launched horizontally at treetop level at everyday speeds, its curved path would quickly intercept the earth and it would crash. But if it were launched at 5 miles per second (18000 mph) its curved path would match the curvature of the earth's surface. If no obstructions or air resistance were present, it would continuously fall without intercepting the earth — it would be in circular orbit. If it were projected at higher speeds it would follow elliptically-shaped orbits — at projection speeds beyond 7 miles per second (25000 mph) would escape the earth altogether. So the essence of launching satellites is to get them up above air drag and boost their tangential speeds high enough so that the curvature of their paths at least matches the curvature of the earth.



A satellite could not only orbit at treetop level (providing it encountered no atmosphere, mountains, or other obstructions), it could orbit the earth in a tunnel below the earth's surface, providing all the air was removed from the tunnel so there would be no drag on the satellite. Question: Would its speed in such a tunnel be greater or less than 5 miles per second?

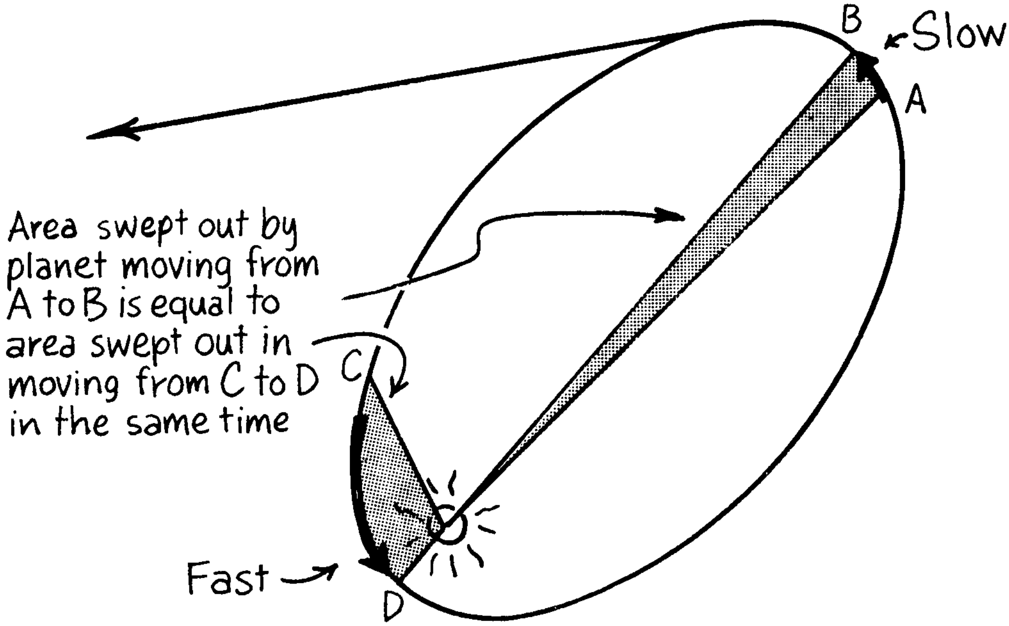


GRAVITY OFF

Kepler's Second Law states that the imaginary line between any planet and the sun sweeps equal areas in equal times as it orbits the sun. If the gravitation between the sun and the planets were somehow switched off and the planets no longer followed elliptical paths, would Kepler's equal area in equal time law still hold true?

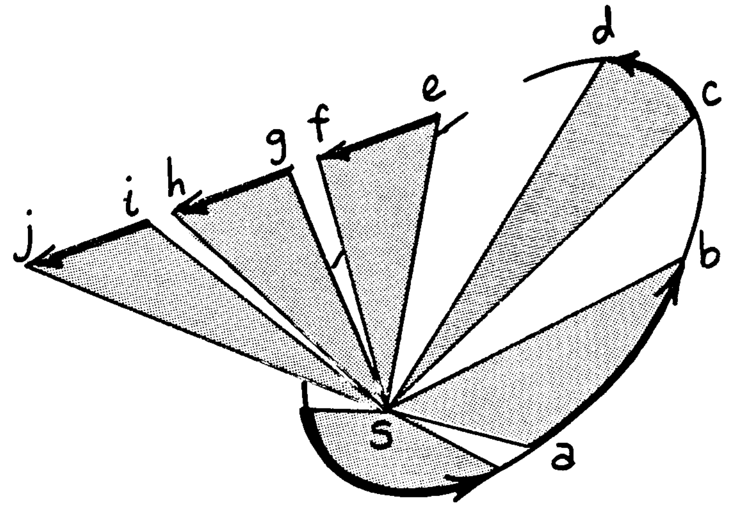
a) Yes, the Second Law would still hold, even with gravity off

b) No, Kepler's laws relate to elliptical orbits produced by gravity. Turn off gravity and Kepler's Second Law is meaningless.

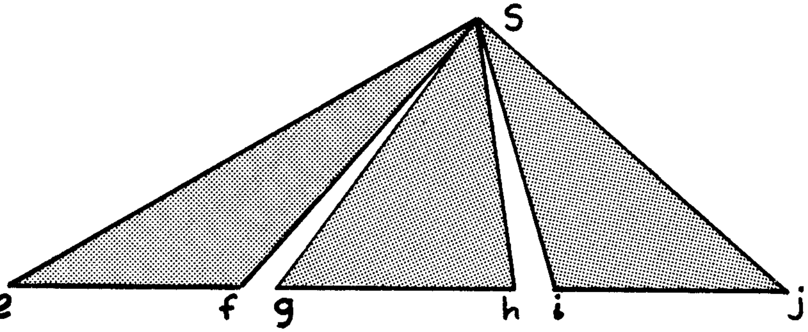


ANSWER: GRAVITY OFF

The answer is: a. Kepler's Second Law states that the imaginary line joining a planet to the sun sweeps out equal areas of space in equal time. This just means that the planet's angular momentum around the sun is unchanging (Remember BALL ON A STRING). Now if gravity is shut off, say when the planet is at position **e**, the planet shoots away along the line **e f g h i j** at constant speed. If the distance between **e** and **f**, **g** and **h**, **i** and **j** are all equal, then the planet must travel between them in equal times.



But the areas of the triangles △ **efs** and △ **ghs** and △ **ijs** are all equal. Why? Because all the triangles have equal bases and a common altitude at s.

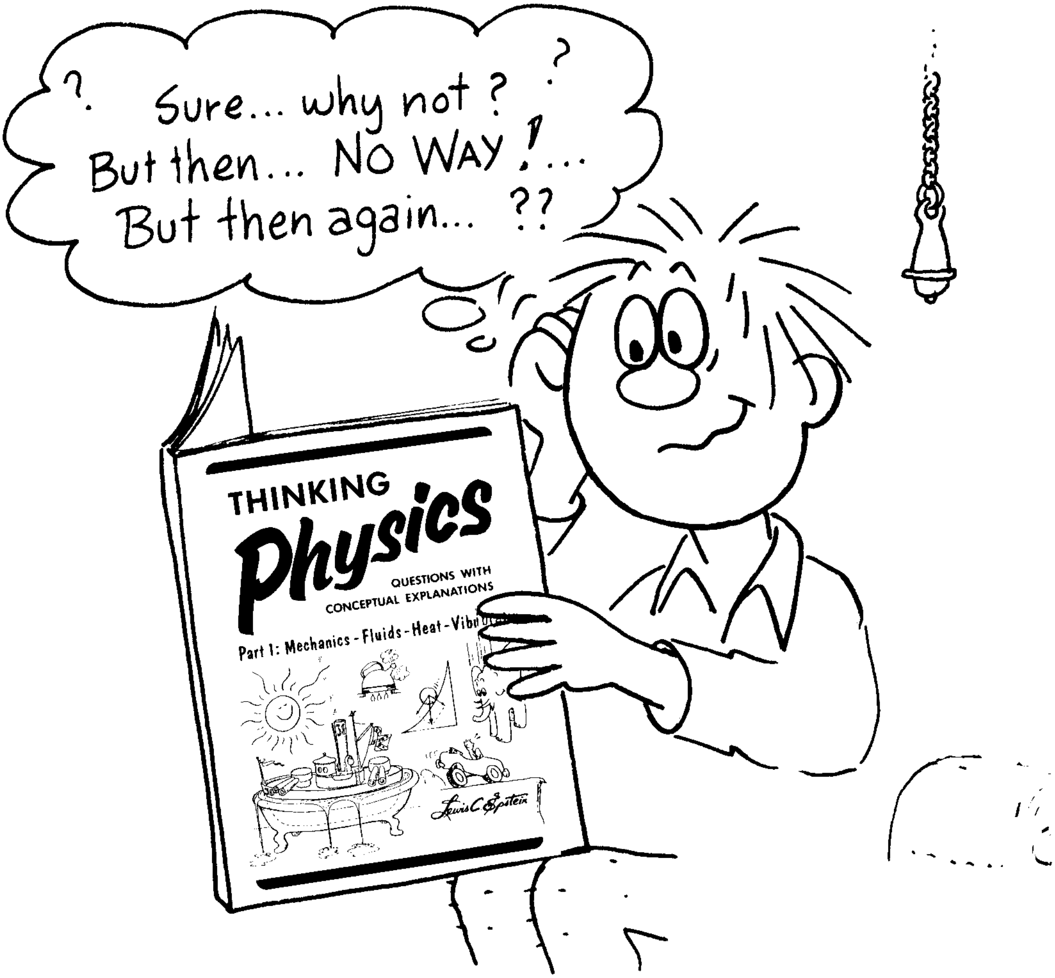


If **ef** = **gh** = **ij** then the area of △**efs** = the area of △**ghs** = the area of △ **ijs**.

SCIENCE FICTION

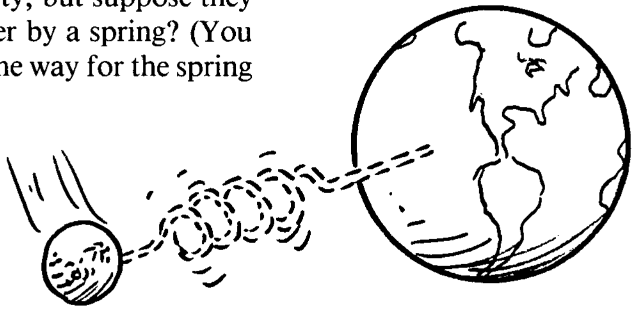
As you move away from the earth its gravity gets weaker. But suppose it did not? Suppose it got stronger? If that fictitious law were so, would it be possible for things, like the moon, to orbit the earth?

a) Yes, just as they presently do
b) Yes, but unlike they presently do
c) No, orbital motion could not occur



ANSWER: SCIENCE FICTION

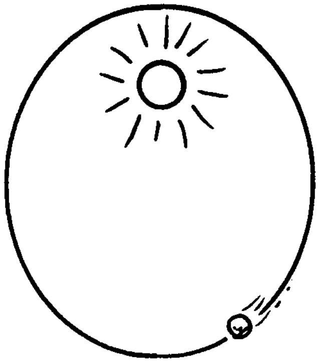
The answer is: b. The earth and moon are held together by the invisible force of gravity, but suppose they were held together by a spring? (You must imagine some way for the spring



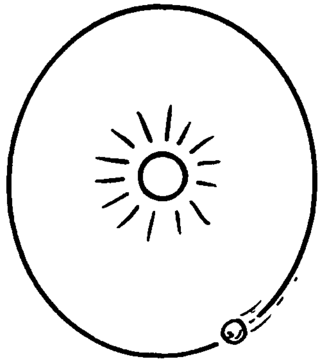
to pivot without getting wrapped around the earth.) Even if the moon were held by a spring it could still orbit the earth. But now the force, being the force of the spring, would get stronger rather than weaker as it was stretched further into space.

Incidentally, if the planets orbited the sun on springs they would still move in elliptical orbits, but the sun would be at the center of the ellipse, not at one focus and all the planets would require about the same time to orbit the sun regardless of the size of their orbits.

Before Newton's time a man named Robert Hooke (a big name in the development of the microscope) had the idea that gravity must work like a spring. Hooke could never understand why Newton got all the glory for the theory of gravity, but as you can see, the spring idea does not lead to the kind of elliptical orbits which are, in fact, found in nature.



Newton's Gravity

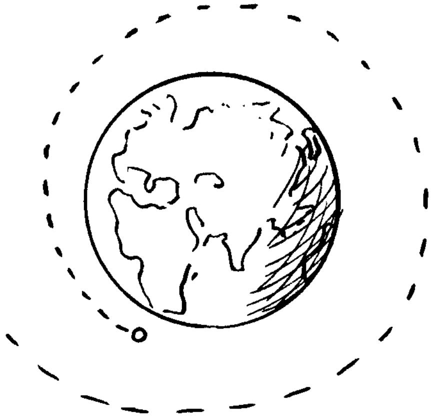


Hooke's Gravity

REENTRY

Sputnik I, the first artificial earth satellite, fell back to earth because friction with the outer part of the earth's atmosphere slowed it down. (Of course, this happens to all low orbiting spacecraft.) As Sputnik spiralled closer and closer to the earth its speed was observed to

a) decrease
b) remain constant
c) increase



ANSWER: REENTRY

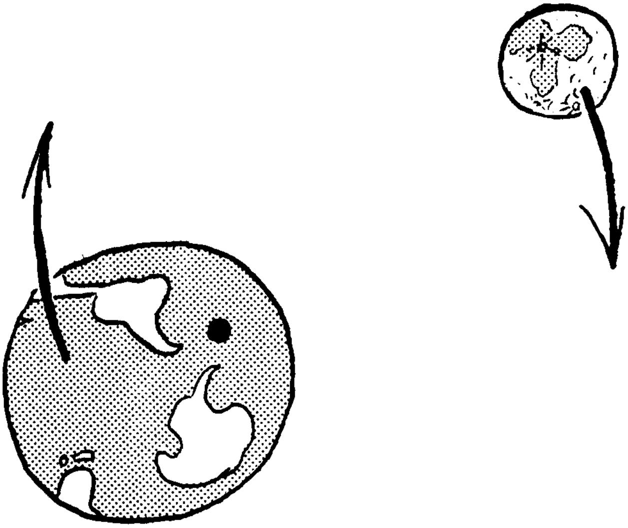
The answer is: c. This very much surprised many people back in 1958 because they were told atmospheric friction was slowing the satellite. The explanation is as follows.

At any height above the earth's surface there is a critical speed. The critical speed is maximum near the earth's surface and is progressively less at higher altitudes. If the spacecraft at a given altitude slows to less than the critical speed for that altitude, it falls closer to the earth and gains speed in doing so — but because of increasing atmospheric friction, it doesn't gain enough speed to attain the even greater speed required for orbit closer to the earth. The speed it in fact gains while approaching the surface of the earth is always too little too late.

BARYCENTER

Which is correct?

a) The moon goes around the center of the earth
b) The earth goes around the center of the moon
c) They both go around some point between the centers



ANSWER: BARYCENTER

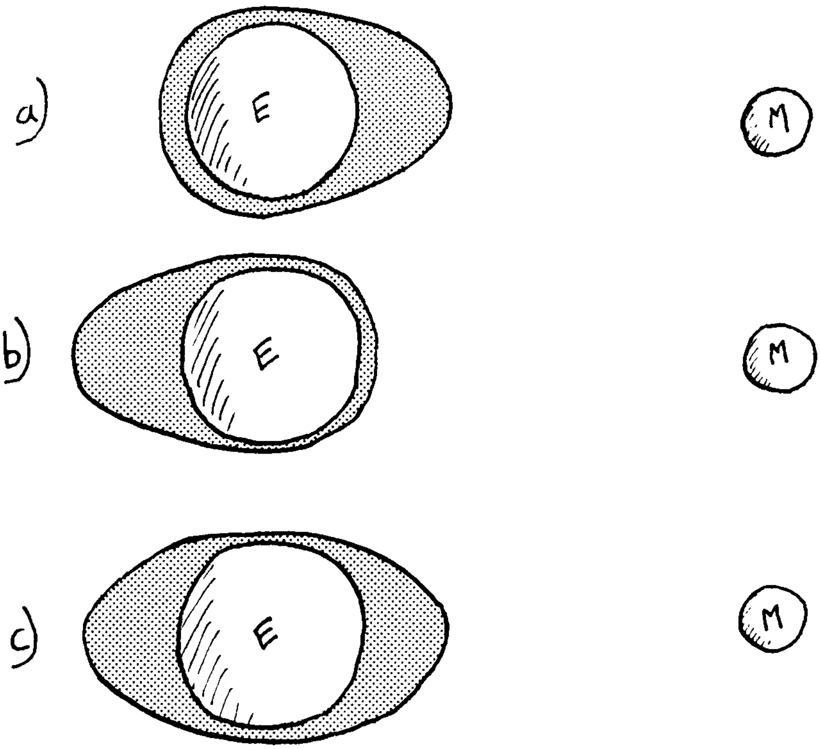
The answer is: c. They must go around their common center of mass, which is much closer to the earth than the moon because the earth has eighty times as much mass as the moon. In fact the common center, called the barycenter, is so close to the earth that it is inside the earth—but not at its center. The barycenter is one thousand miles below the earth's surface. The diameter of the earth is 8000 miles and the distance to the moon is about 30 earth diameters.

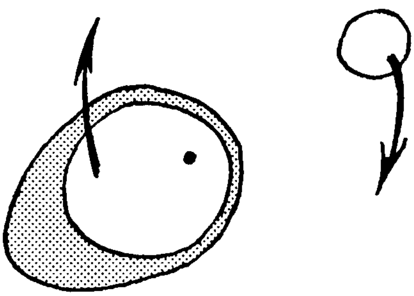
How long does it take the earth to orbit around the barycenter? Exactly as long as it takes the moon to go around it—one month.

OCEAN TIDE

The ocean tide produced by the moon is deepest on the side of the earth

a) under the moon
b) away from the moon
c) about equally deep on both sides

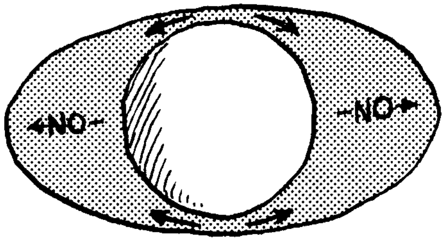




ANSWER: OCEAN TIDE

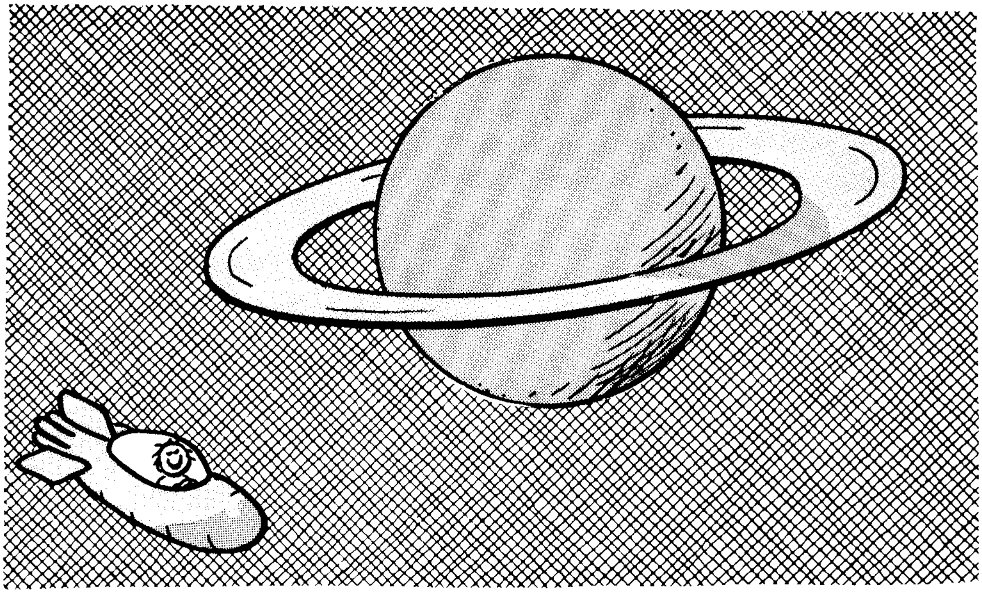
The answer is: c. You might think the moon's gravity should pull the water to the side of the earth near the moon. But then again you might think that as the earth pivots around the barycenter each month, the water would be thrown to the side farthest from the barycenter, which is the side away from the moon.

Actually both of these thoughts are correct. On the side near the moon lunar gravity is strongest so the water is pulled towards the moon. On the side farthest from the barycenter the centrifuge effect is strongest so the water is also thrown out there. The surface of the ocean ends up being shaped like a football, one end towards the moon, one end away. But don't suppose the water is actually lifted by gravity or the centrifuge effect. The water is slid off regions of the earth where the moon is on the horizon and accumulated on the face looking towards and the face looking away from the moon.



What about the force of the earth's own gravity and the centrifuge effect of the earth's daily spin around its center? These forces must be stronger than those due to the moon's gravity and the monthly spin around the barycenter. Yes, they are stronger. But they act equivalently all around the earth, so whatever they do, they do the same all around the earth. On the other hand, the effect of the moon's gravity and the barycenter spin are not the same all around the earth. That's why the water depth is not the same all around the earth.

SATURN'S RINGS

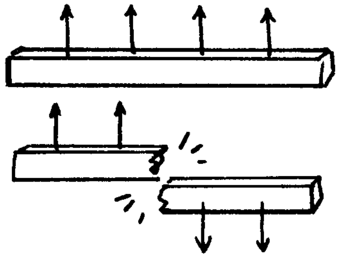


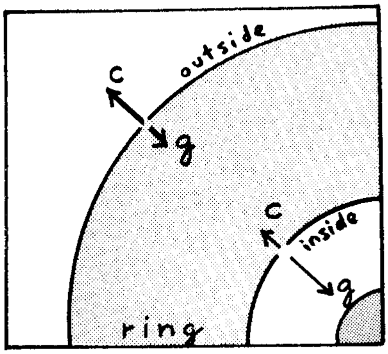
Over a century ago, J.C. Maxwell calculated that if Saturn's rings were cut from a piece of sheet metal they would not be strong enough to withstand the tidal tension or gravitational gradient tension that Saturn would put on them and would, therefore, rip apart. But suppose the rings were cut from a piece of thick-plate, rather than thin-sheet, iron. Might the thick-plate hold? The thick-plate would

a) fail as easily as the thin-sheet
b) fail more easily than the thin-sheet
c) not fail as easily as the thin-sheet

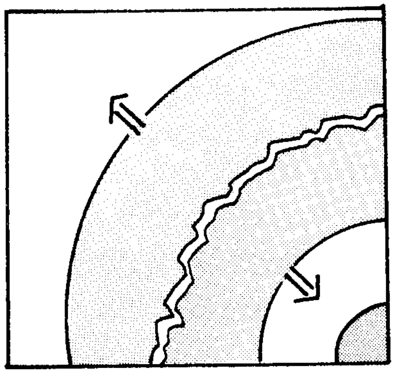
ANSWER: SATURN'S RINGS

The answer is: a. First of all, let us understand why material breaks or fails. Material does not break simply because of force. A uniform force applied to a bar for example simply makes the bar accelerate in the direction of the force. Material breaks because DIFFERENT forces are applied to different parts of the material. The force DIFFERENCES produce tensions, compressions or shears and it is these stresses that cause material to fail.

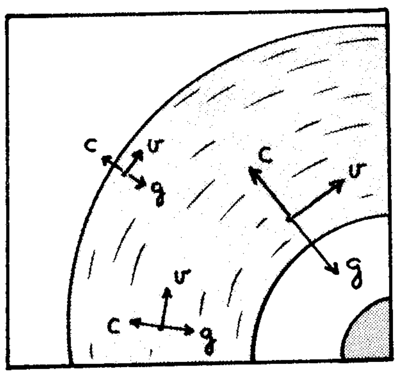




Now suppose that Saturn's rings were solid discs. Saturn will exert a greater gravitational force on the inside of the disc than on the outside and this puts a tension strain into the disc that tends to pull it apart. The gravitational stress is proportional to the mass of the ring. If the solid disc ring is made to spin this only makes the strain worse because there is more centrifugal force on the outer part of the disc than on the inner part. (This is why flywheels sometimes explode.) The centripetal stress is also proportional to the mass of the ring. So increasing the mass of the ring by going from sheet to plate-iron will not help. The rings would be stronger, but the stress on them would also be stronger. So a solid ring about Saturn, whether thick or thin, would be ripped apart.



Maxwell decided the rings could not be solid discs. They had to be made of many individual particles. That way each particle could orbit Saturn with its own individual speed adjusted to the gravitational force at its particular distance from the planet. So the inner part of Saturn's rings orbit faster than the outer parts, and all stress is avoided.



HOLE MASS

The mass of a "black hole" must be infinite, or at least nearly infinite.

a) True
b) False

ANSWER: HOLE MASS

The answer is: b. If an object is moving fast enough it can escape from a planet or star. If it is not moving fast enough it falls back. The minimum speed required to get away is called ESCAPE VELOCITY. The larger the mass of the planet or star, the larger the escape velocity — provided the planet's size does not change.

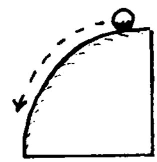
Now, a black hole is a thing for which the escape velocity is larger than the speed of light. But the speed of light is not infinite. It is a large number, but it is a finite number. The mass of the black hole is also finite and not infinite. In fact, black holes can be made from very small masses if the mass is sufficiently compressed. If you could figure out how to compress a mass and make a black hole it would be a fantastic science fair project!

MORE QUESTIONS (WITHOUT EXPLANATIONS)

You're on your own with these questions which parallel those on the preceding pages. Think Physics!

1. Suppose you wish to average 40 mph on a particular trip and find that when you are half way to your destination you have averaged 30 mph. How fast should you travel the remaining half of your trip to attain the overall average of 40 mph?
   a) 50 mph b) 60 mph c) 70 mph d) 80 mph e) none of these

2. A dragster accelerates from zero to 60 mph in a distance D and time T. Another dragster accelerates from zero to 60 mph in a distance "?" and time $2T$. That is, it took the second dragster twice as long to get to 60 mph. How much distance did the second dragster cover while getting up to 60 mph?
   a) ¼D b) ½D c) D d) 2D e) 4D

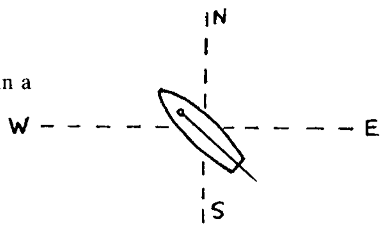


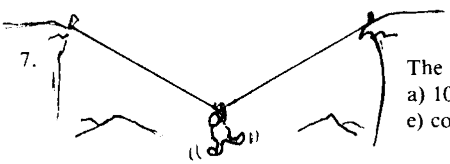
3. As the ball rolls down this hill
   a) its speed increases and acceleration decreases
   b) its speed decreases and acceleration increases
   c) both increase d) both remain constant e) both decrease

4. As an object freely falls (zero air resistance) its velocity increases and its acceleration
   a) increases b) decreases c) remains constant

5. As an object falls through air and *is* affected by air resistance its velocity increases and its acceleration
   a) increases b) decreases c) remains constant

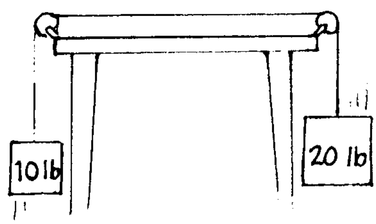
6. The sailboat shown will sail fastest when the wind blows in a direction from the
   a) north b) east c) south d) west e) none of these



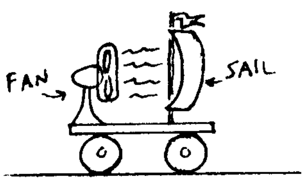


7. The tension in the rope that supports the 200 lb. man is about
   a) 100 lb b) 200 lb c) 400 lb d) 800 lb
   e) considerably more than 800 lb

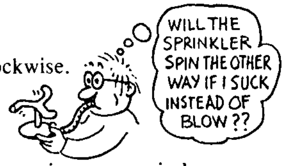
8. The tension in the string that joins the downward accelerating 20-lb weight and the upward accelerating 10-lb weight is
   a) less than 10 lb
   b) 10 lb
   c) more than 10 lb but less than 20 lb
   d) 20 lb
   e) more than 20 lb



9. The cart will
   a) accelerate toward the left
   b) accelerate toward the right
   c) not accelerate



10. When air is blown into the garden sprinkler it spins clockwise. When air is sucked the sprinkler spins
a) also clockwise b) anti-clockwise c) not at all



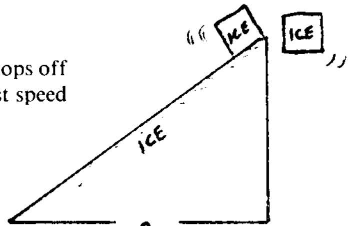
11. Suppose you are driving along the highway and a bug splatters into your windshield. Which experiences the greatest impact force?
a) the bug b) the windshield c) both the same

12. Suppose that when you jump from an elevated position to the ground below you bend your knees upon making contact and thereby extend the time your momentum is reduced by 10 times that of a stiff-legged abrupt landing. Then the average forces your body experiences upon landing are reduced
a) less than 10 times b) 10 times c) more than 10 times

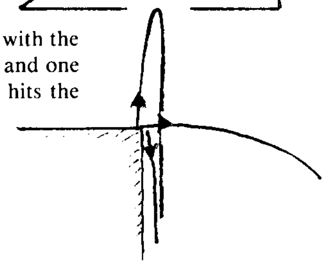
13. A Cadillac and a Volkswagen rolling down a hill at the same speed are forced to a stop. Compared to the force that halts the Volkswagen, the force to bring the Cadillac to rest
a) must be greater b) must be the same c) may be less

14. When a 10-lb object falls from rest to the ground 10 ft below, it strikes with an impact of about
a) 10 lb b) 50 lb c) 100 lb d) can't tell

15. One block of ice slides down the plane while the other drops off the end. The block that reaches ground with the greatest speed is the
a) sliding block
b) block that drops
c) both the same



16. From the top of a building we throw three rocks each with the same speed. One is thrown straight up, one sideways, and one straight down. Which rock is moving fastest when it hits the ground?
a) the one thrown up
b) the one thrown sideways
c) the one thrown down
d) all hit with the same speed



17. A rock is dropped from the top of a tall tower. Half a second later a second rock is dropped. The separation between the rocks as they fall
a) increases b) decreases c) remains constant

18. In the above situation the second rock hits the ground
a) less than half a second after the first
b) a half second after the first
c) more than a half second after the first

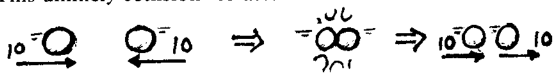
19. Two rocks are simultaneously dropped from locations one a foot higher than the other. As they fall the separation between the rocks
a) increases b) decreases c) remains constant

20. In the above situation there is a time lapse between impacts as the rocks hit the ground. Suppose the rocks are dropped the same way, one a foot higher than the other, but from a greater height. Then the time lapse between impacts
a) increases b) decreases c) remains the same

21. If the momentum of a falling body is doubled, its kinetic energy is
a) doubled b) quadrupled c) can't tell

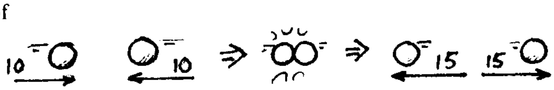
22. A driver going 10 mph hits the brakes and skids 25 feet to a stop. If she were instead going 40 mph the car would skid
a) 100 ft. b) 200 ft. c) 400 ft. d) more than 400 ft.

23. Suppose a pair of pool balls moving at 10 ft/s collide, and then roll off in the *same* direction, each at 10 ft/s. This unlikely collision violates the conservation of



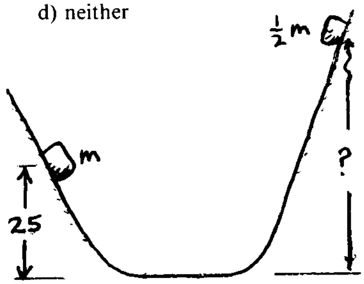
a) kinetic energy b) momentum c) both d) neither

24. Suppose in the preceding situation that after collision the two balls bounced apart each with a speed of 15 ft/s. In this unlikely collision there would be a violation of the conservation of



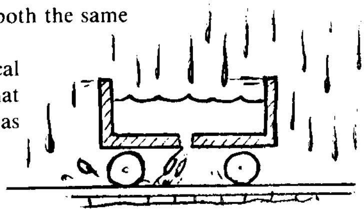
a) kinetic energy b) momentum c) both d) neither

25. A lump of clay slides down a hill from a height of 25 ft. A second lump of clay only half as heavy as the first slides down another hill and the two lumps come to a dead stop when they collide at the bottom of the hills. How high is the hill from which the small lump slid?
a) 37½ ft. b) 50 ft. c) 75 ft. d) 100 ft.
e) can't say



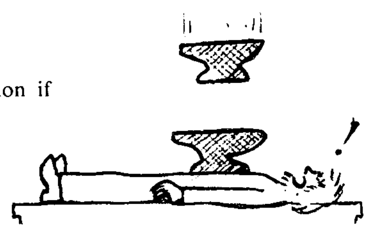
26. A one-ton pickup truck going 12 mph drives into a giant haystack. An identical one-ton pickup, loaded with one ton of hay bales and going only 6 mph, drives into the same haystack. Which truck penetrates farther into the haystack before stopping?
a) the fast empty truck b) the slow loaded truck c) both the same

27. A railroad car is rolling without friction in a vertical downpour. A drain plug is opened in the bottom of the car that allows the accumulating water to run out. If the water drains as fast as it accumulates the speed of the car
a) increases b) decreases c) remains the same

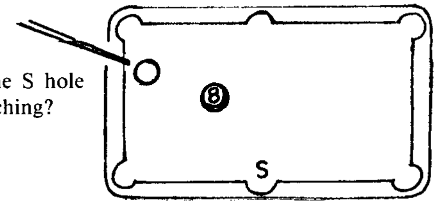


28. A gun recoils when it is fired. So the gun and the bullet each get some kinetic energy and momentum. Both the gun and bullet get equal
a) but opposite amounts of momentum
b) amounts of kinetic energy
c) both
d) neither

29. Would the anvil afford much protection if another anvil were dropped on it?
a) Yes b) No



30. The hustler is going to try sinking the 8 ball in the S hole (without english). Is he in particular danger of scratching?
a) Yes b) No



31. If the speed of a thing changes, then its velocity changes. And if the velocity of a thing changes, then its speed
a) must change also
b) may or may not change
c) must not change

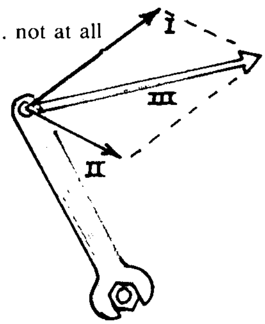
32. The net force that acts on a car traveling in a circle at constant speed on a flat surface is
a) in the direction the car is traveling
b) in the direction of the radius of the circle
c) equal to zero

33. The driver in a car turning in a given radius and moving with a given speed experiences a certain centrifugal force. This force will be MOST increased by
a) doubling the speed of the car
b) doubling the radius in which it turns
c) halving the radius in which it turns
d) "a" and "b" produce exactly the same effect
e) "a" and "c" produce exactly the same effect

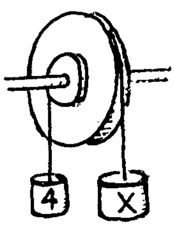
34. An object dropped down a deep mine shaft at the earth's equator will be slightly deflected to the
a) north b) east c) south d) west e) . . . not at all

35. An object dropped down a deep mine shaft at the north pole will be slightly deflected to the
a) north b) east c) south d) west e) . . . not at all

36. We know if forces I and II act together, they are equivalent to force III. Now, is the torque on the nut produced by force I and force II acting together *always* equivalent to the torque produced by force III?
a) Yes b) No

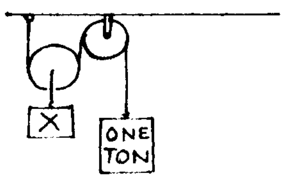


37.

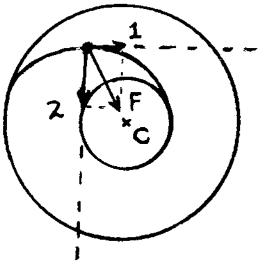


The rim of a wheel is 16 ft. in circumference and the hub is 8 ft. in circumference. A 4-lb weight is wound around and hung from the left side of the hub. What weight must be wound around and hung from the right side of the rim to balance the wheel so it will not turn?
a) 2 lb. b) 3.14 lb. c) 6 lb. d) 8 lb.

38. Two weights are suspended from a ceiling by means of a cord and two pulleys as illustrated. If the one-ton weight is held in balance by X, then X weighs
a) 1 ton b) 2 tons c) ½ ton d) ⅓ ton e) 3 tons



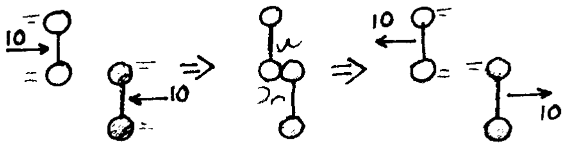
39. The answer to BALL ON A STRING stated that no torque acted on the ball because the force was directed to the center C and therefore had no lever arm. But aren't there lever arms for Components 1 and 2? Why then do we say no torque exists?
a) But there are *no* lever arms about C for Components 1 and 2!
b) Components 1 and 2 are perpendicular to each other and cancel about C
c) Torques due to Components 1 and 2 cancel each other
d) Misprint: A net torque certainly does exist!



40. An object isolated in space and not interacting with any external agency can by internal interactions change its own
a) linear momentum b) linear kinetic energy c) both d) neither

41. It is possible for the same isolated object in the preceding question to change its own
a) angular momentum b) rotational kinetic energy c) both d) neither

42. The illustrated collision between the dumbbells violates conservation of
a) kinetic energy
b) momentum
c) angular momentum
d) all of these
e) none of these



43. When a 4-wheel-drive jeep accelerates from rest, it noses
a) upward b) downward c) not at all

44. The bob of a swinging pendulum has its greatest speed at the bottom of its swing and its greatest acceleration
a) at the bottom also
b) at its highest point where it momentarily stops
c) none of these

45. A marksman fires at a distant target. If it takes one second for his bullet to get there, he should aim above the target
a) 16 ft. b) 32 ft. c) can't say unless we know the target is at eye level

46. A ball is thrown horizontally at 40 ft/s. from an elevated position and one second later strikes the *ground* at a speed of about
a) 32 ft/s. b) 40 ft/s. c) 50 ft/s.

47. Suppose a planet orbits about a giant star that begins to collapse to a black hole. After the collapse, the orbital radius for the planet is
a) smaller b) larger c) unchanged d) non-existent

48. Strictly speaking, in the ground floor lobby of a giant skyscraper you weigh
a) a bit less b) a bit more c) the same as outside the skyscraper

49. The moon does not fall to earth because
a) it is in the earth's gravitational field
b) the net force on it is zero
c) it is beyond the main pull of the earth's gravity
d) it is being pulled by the sun and planets as well as by the earth
e) all of the above
f) none of the above

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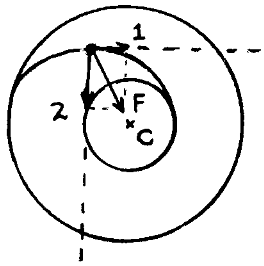

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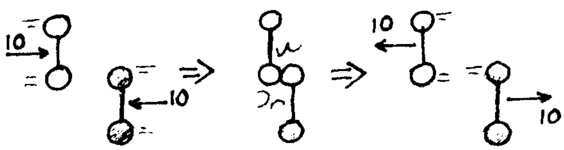

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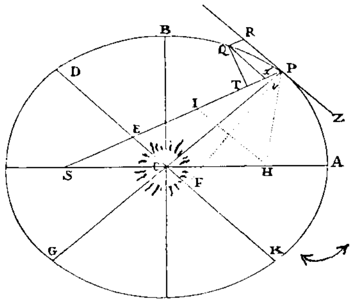
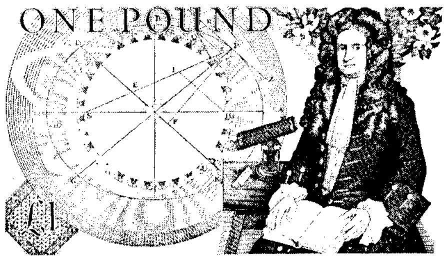
f) none of the above

50. Here is a one pound Bank of England note, British money, approximately equal to \$2.00 in 1979. Take a careful look at the elliptical orbit of the planet G, D, B, P, K with the sun at C. This diagram represents
a) Newton's theory of gravity
b) Hooke's theory of gravity





51. The earth's orbit about the sun is slightly elliptical, the earth being closest to the sun in December and farthest in June. The orbital speed of the earth is therefore
a) greater in December
b) greater in June
c) the same throughout the year

52. A planet is found on the average to orbit the sun a bit faster than it should according to Newton's laws. It is suspected an undiscovered planet is responsible. The orbit of the undiscovered planet lies
a) inside the orbit of the fast-moving planet
b) outside the orbit of the fast-moving planet

53. Suppose a US and USSR space craft are both freely coasting in circular orbits moving in the same direction. If the altitude of the USSR craft is 100 miles, and the altitude of the US craft is 110 miles, then the
a) US craft gradually pulls ahead of the USSR craft
b) USSR craft gradually pulls ahead of the US craft
c) crafts remain abreast of each other