NEXT-TIME QUESTION

CONCEPTUAL Physics

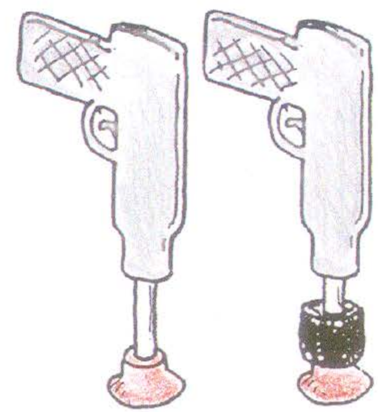
Two identical spring-loaded dart guns are simultaneously fired straight downward. One fires a regular dart; the other a weighted dart.

Which dart hits the ground first?

a) The regular dart.

b) The weighted dart.

c) It's a tie.



thanx to Dean Baird

Hewitt Drew it!

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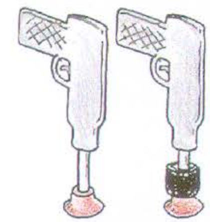
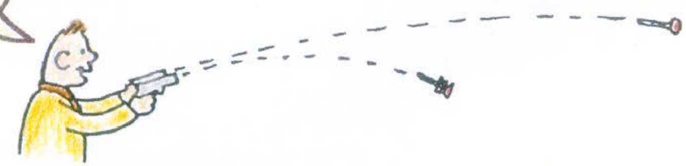


Answer: a

The springs in both guns apply the same amount of force to the darts, but the regular dart has less inertia and therefore has greater acceleration in the gun. So it emerges with a greater speed and wins the race!

FIRE THE DARTS HORIZONTALLY AND YOU'LL EASILY SEE THE LIGHTER ONE GOES FARTHER AND FASTER!



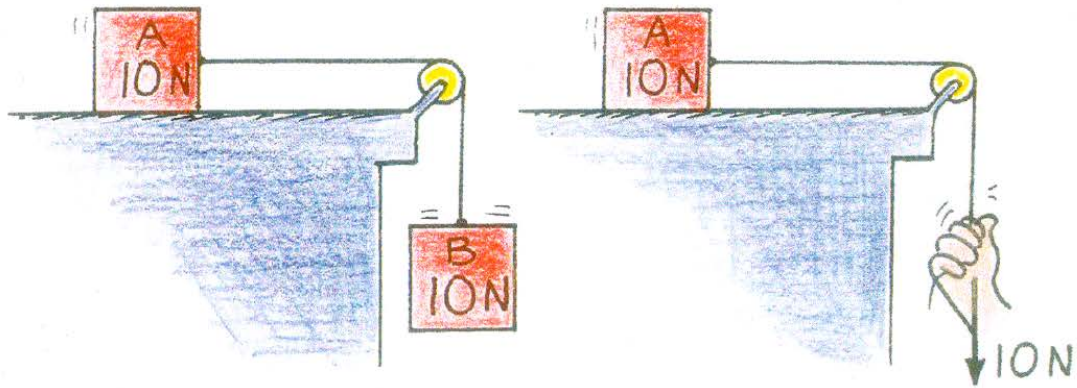
Hewitt Drew it!

CONCEPTUAL Physics

Chapter 4: Newton's Second Law of Motion

Caveat: if the height of the guns is large enough, the heavy dart wins

Next-Time Question



In both systems an applied force of 10 N causes Block A to accelerate. The acceleration of Block A is

a) the same in both systems.
b) greater in the one-block system.
c) greater in the two-block system.

The tension in the string is

d) the same in both systems.
e) greater in the one-block system.
f) greater in the two-block system.

Hewitt Drew it!

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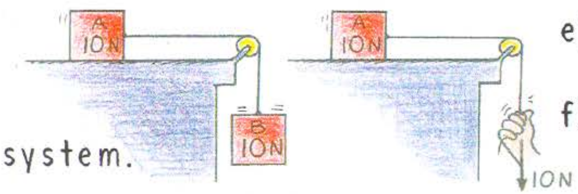


The tension in the string is

d) the same in both systems.
e) greater in the one-block system.
f) greater in the two-block system.

Answers: b, e

Although the applied force is the same in both systems, the mass being accelerated is different. In the single-block system, only Block A accelerates. In the two-block system, both Blocks A and B accelerate. Twice as much mass in the two-block system results in half as much acceleration. So acceleration is greater for the one-block system.

By Newton's second law, $a = \frac{F_{net}}{m}$, the same force acting on half the mass produces twice the acceleration.

String tension is 10 N in the one-block system—but not in the two-block system (if it were 10 N in the two-block system, F_{net} on hanging Block B would be zero—with *no* acceleration). Since acceleration of the two-block system is half, string tension in the two-block system is half.

Block A is pulled with 5 N of string tension.

Hewitt Drew it!

Chapter 5: Newton's Third Law

First, let's clarify notion of a force:

Previously defined force as a push or pull. Better to think of force as an **interaction** between two objects.

Eg. I push on the table, it pushes back on me with an equal and opposite force on me. If on ice (no friction), I'd slide backwards. This force pair constitutes a single interaction. (More egs very soon)

You can't push anything without it pushing back on you !

Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first.

Often called "**action-reaction**"

Eg. Leaning against a wall.

You push against the wall. The wall is also pushing on you, equally hard.

Now place a piece of paper between the wall and hand. Push on it – it doesn't accelerate → must be zero net force. The wall is pushing equally as hard (normal force) on the paper in the opposite direction to your hand, resulting in zero *Fnet*.

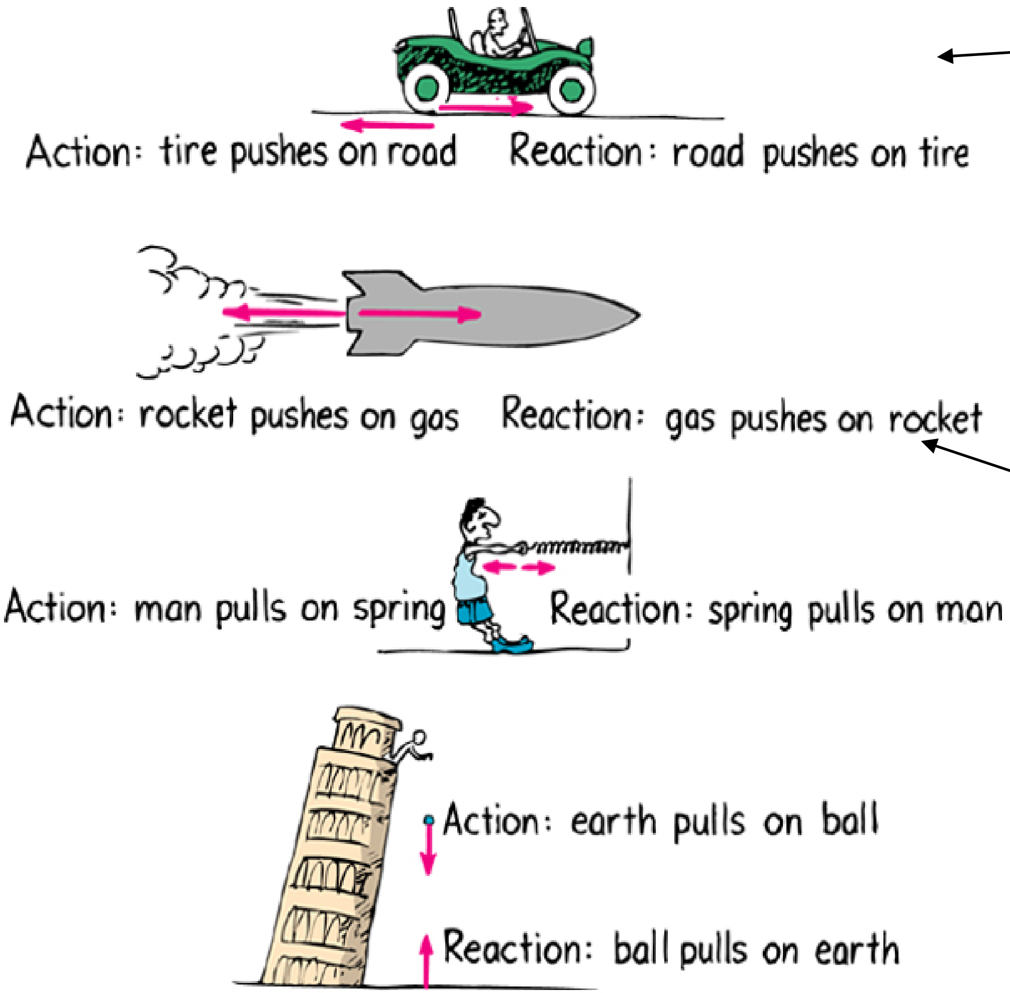
This is more evident when hold a balloon against the wall – it is squashed on both sides.

Eg. You pull on a cart. It accelerates. The cart pulls back on you (you feel the rope get tighter). Can call your pull the "action" and cart's pull the "reaction". Or, the other way around.

• Newton's 3rd law means that **forces always come in action-reaction pairs**. It doesn't matter which is called the action and which is called the reaction.

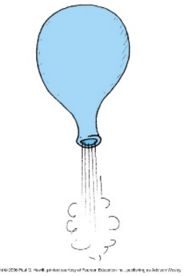
• Note: Action-reaction pairs *never* act on the same object

Examples of action-reaction force pairs



In fact it is the road's push that makes the car go forward. Same when we walk – push on floor, floor pushes us forward. (These forces are frictional).

Fun Demo: blow up a balloon and release it. Same principle as rocket



Question

a) What are the action and reaction forces for the case of a bat striking a ball?

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Answer:

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Reaction: ball’s hit on the bat

Or, the other way around

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Or, the other way around.

b) What are the action-reaction pairs once the ball is in the air?

Question

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Action: bat's hit on the ball

Reaction: ball's hit on the bat

Or, the other way around.

b) What are the action-reaction pairs once the ball is in the air?

First note there are two interactions: (i) one with the earth's gravity and (ii) the other with the air.

(i) Action: Earth pulls down on ball (weight)

Reaction: ball pulls up on Earth.

(ii) Action: Air pushes ball backwards

Reaction: Ball pushes air forwards

Whenever one object exerts a force on a second object, the second object exerts a force on the first that

- is opposite in direction.
- is equal in magnitude.
- occurs at the same time.
- All of these.

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Question:

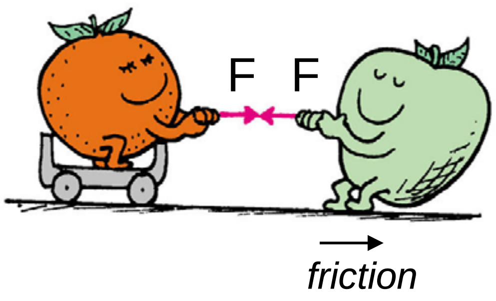
Since action and reaction are equal and opposite, why don't they cancel to zero?

Answer: They act on different objects.

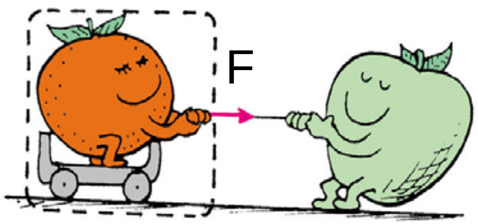
If you define the "system" to be both objects, then action-reaction forces within the system do cancel.

Let's explore this a bit more…

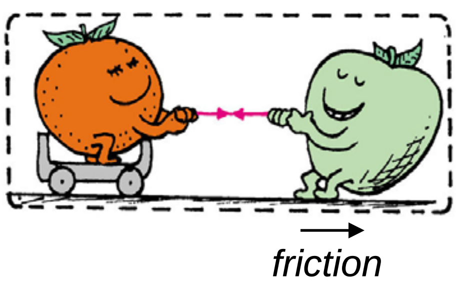
Another example: Let's consider the force pair between the "apple" and "orange" below:



Apple exerts a force F on orange, so orange accelerates. Simultaneously, orange exerts equal force in the opposite dir. on the apple (but apple may not accelerate because of friction on his feet).



Consider now orange as the "system". Apple's pull on orange, F, is an external force and accelerates the system(=orange).



Consider the apple+orange as one system. Then the only external force is friction. Action and reaction are both within the system and cancel to zero.

If friction =0, the acc. of system =0 (eg if they were on ice). Apple and orange would move closer to each other but system's center of mass wouldn't move.

If friction non-zero, system accelerates to the right.

Flash video Nt III.1

Questions

(1) A pen at rest. It is made up of millions of molecules, all pulling on each other - cohesive inter-atomic forces present in any solid. Why doesn't the pen accelerate spontaneously due to these forces?

Because each of these is part of an action-reaction pair within the pen. They always add to zero within the system. The pen will remain at rest unless an external force acts on it.

(2) The earth's gravity pulls on the moon. What is the reaction force to this?

Ans: The moon's pull on the earth.

Note: It is better to think of this as **one interaction** – the Earth and moon simultaneously pull on each other (action-reaction), each with the same amount of gravitational force.

(3) Consider for simplicity, the earth and moon as the only bodies in the universe.

a) What is the net force on the earth?

The moon's gravitational pull

b) What is the net force on the earth+moon system?

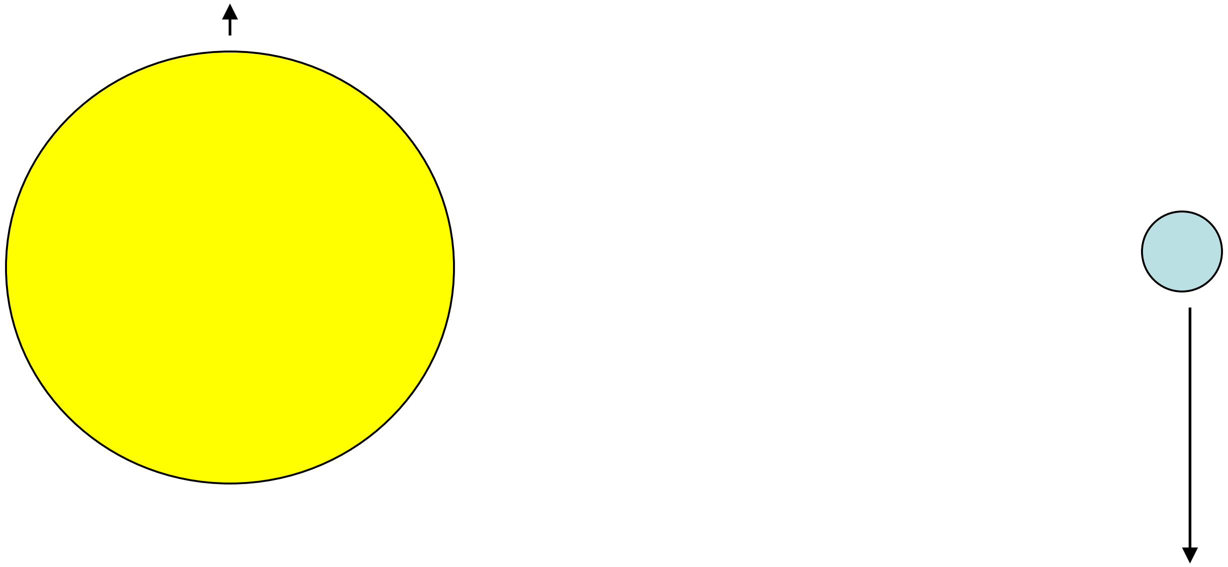
0. Action and reaction cancel within the system

Brief astronomy interlude:

What is our primary evidence for the existence of planets outside our solar system?

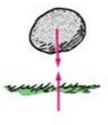
A little outdated… recently several extrasolar planets have been directly imaged

Reaction force of planet on observable star causes small oscillations in (deviations from) it's regular motion (wobbling).



More on action-reaction…

- If all forces come in pairs, then how come the earth doesn't accelerate towards apples falling from trees?



Actually it does! But it is not noticeable or measurable because the earth's mass is so large:

mass of apple

The earth exerts force = mg on the apple. This interaction gives apple acc = F/m = 9.8 m/s^2.

The apple exerts just as much force on the earth, mg. But to get acc of earth, this gets divided by M, the mass of the earth: earth's acc. = $(mg)/M$ ~ tiny.

• Recoil from a fired rifle: the force exerted on the bullet is just as large as the reaction force on the rifle, so the rifle kicks (recoils).

But the acceleration of the rifle is much less than that of the bullet, because its mass (inertia) is much greater.

Flash video NTIII.2

$a_{bullet} = F/m_{bullet}$

$a_{\text{rifle}} = F/m_{rifle}$

Since $m_{rifle} >> m_{bullet}$, but same F, $a_{rifle} << a_{bullet}$

• Same principle behind a rocket (or earlier balloon demo) – it continually recoils from the ejected gas. (Does *not* need atmosphere to push against, as thought in 1900's…)

The force that propels a heavy truck along a highway is provided by

- gravity.
- Newton's laws of motion.
- the highway pushing back on the wheels of the truck.
- the air drag acting on the truck.

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Summary of Newton's Three Laws

- An object tends to remain at rest, or, if moving, to continue moving at constant speed in a straight line **(1st Law).**

Objects tend to resist changes in motion (**inertia**) – **mass** measures this.

- **(2nd Law)** When there is a net force on an object, it will accelerate: ***a = Fnet/m,*** *a* is in the **same direction as *Fnet***.

- Falling in vacuum (**free-fall**), the only force is gravity, *mg*, and every object falls at the same rate, ***g =9.8 m/s²***

- Falling in air, ***Fnet = mg – R***, acceleration is *less than g*. R is greater for objects with more frontal area, and for larger speeds. **Terminal speed** is reached when R = mg, so is later for heavier objects, which therefore accelerate more and hit ground faster.

- **(3rd Law)** Whenever any object A exerts force on object B, B exerts equal and opposite force on A. It is a **single interaction**, forces come in pairs. Action and reaction always act on different objects.

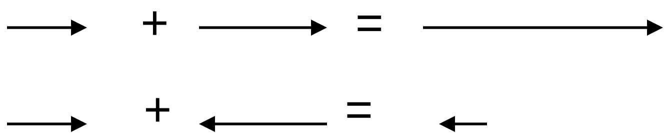
Vectors

- Vector = quantity with magnitude and direction, eg velocity, force, acceleration….
  Can represent by an arrow (length indicates magnitude)

- Scalar -has magnitude only, eg speed, mass, volume..

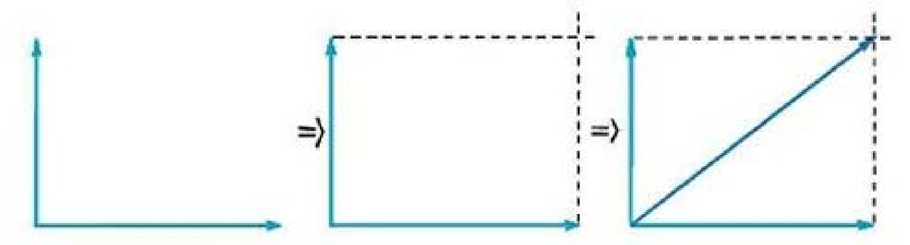
- Often we want to add vectors: eg if want to find net force, when several forces acting, or, to find resulting velocity when a plane is headed in a certain direction, but there is a wind blowing in another..

- If the two vectors are in the same direction – can just add. If in opposite directions, subtract.



- More generally, use **parallellogram rule** to add to get the **resultant**: construct such that two adjacent sides are the two vectors – the diagonal shows the resultant.

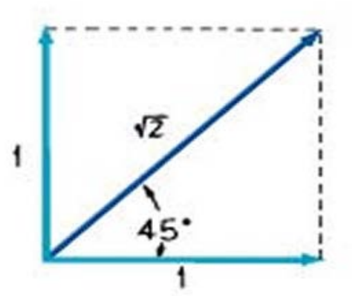
Simplest case: when the two vectors to be added are at right angles:



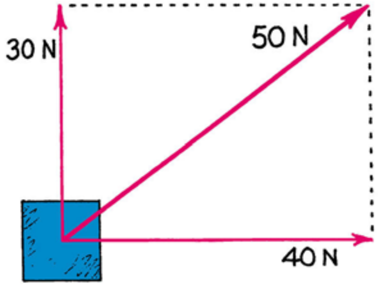
The parallelogram is a rectangle in this case.

…vectors…

- When the two vectors are at right-angles and have the same magnitude, then the parallelogram is a square:



• Pythagorean triples can also simplify addition: eg. Top view of 30 N and 40 N horizontal forces pulling on a box, gives a resultant force of 50 N in direction shown:



Flash video NtIII.3

• Vector components: “resolve” any vector into two components at right-angles to each other. We won’t study this in this course, but do read about it in your book if you are interested!

You run horizontally at 4 m/s in a vertically falling rain that falls at 4 m/s. Relative to you, the raindrops are falling at an angle of

- 0°.
- 45°.
- 53°.
- 90°.

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The resultant of a 30-N force and a 40-N force cannot possibly be

- 10 N.
- 50 N.
- 70 N.
- 80 N.

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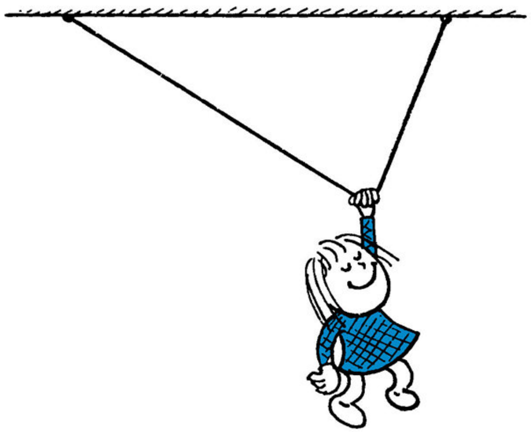
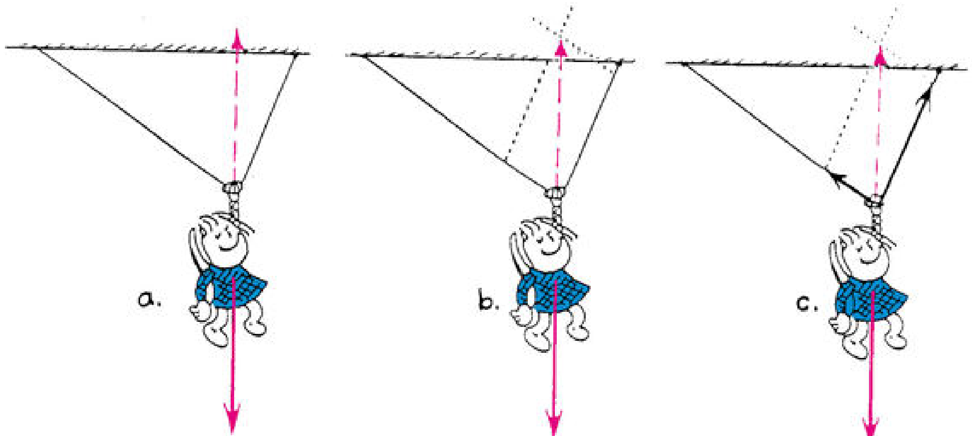
Example



The girl is hanging, at rest, from a clothes line. Which side of the line is more likely to break?

First, identify forces: Three forces are acting on her – downward weight, tension in left line, and tension in right line. The question is asking, which tension is greater.

Because she's at rest, the net force must be 0. The upward tensions must sum to her weight. Make parallelogram with sides along the rope tensions, whose diagonal is the desired upward resultant:



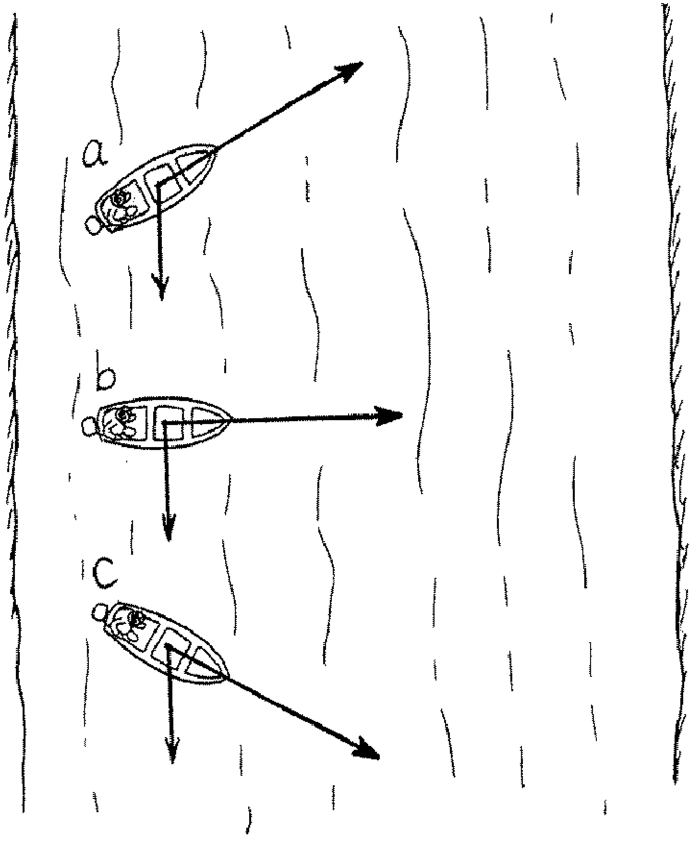
So, larger tension in the right line (more vertical), so it is more likely to break.

Example: velocity vectors

Motorboats cross a river pointing in the three directions shown. The boats all have the same speed relative to the water, and all experience the same water flow.

Which boat reaches the opposite shore first?

1. a 2. b 3. c



Hint: note, this is asking a “time” question, not a “where” question.

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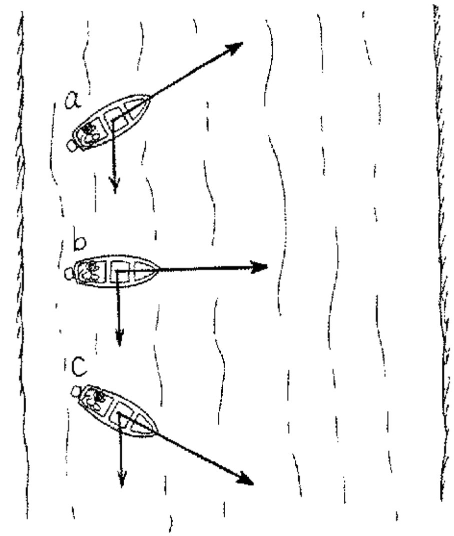


Which boat reaches the opposite shore first?

1. a ✔**2. b** 3. c

Answer: b, the one headed

straight across, since the velocity of the motor is entirely straight across, not “wasted” by going up or down the river. Note that it will end up downstream.

Another question: Which boat provides the fastest ride?

Answer: c, because it has the largest resultant velocity vector (sketch the parallelograms to see)

Yet another question: Which boat travels the shortest distance?

Answer: a, the resultant velocity vector is straight across, perpendicular to the current.

Example

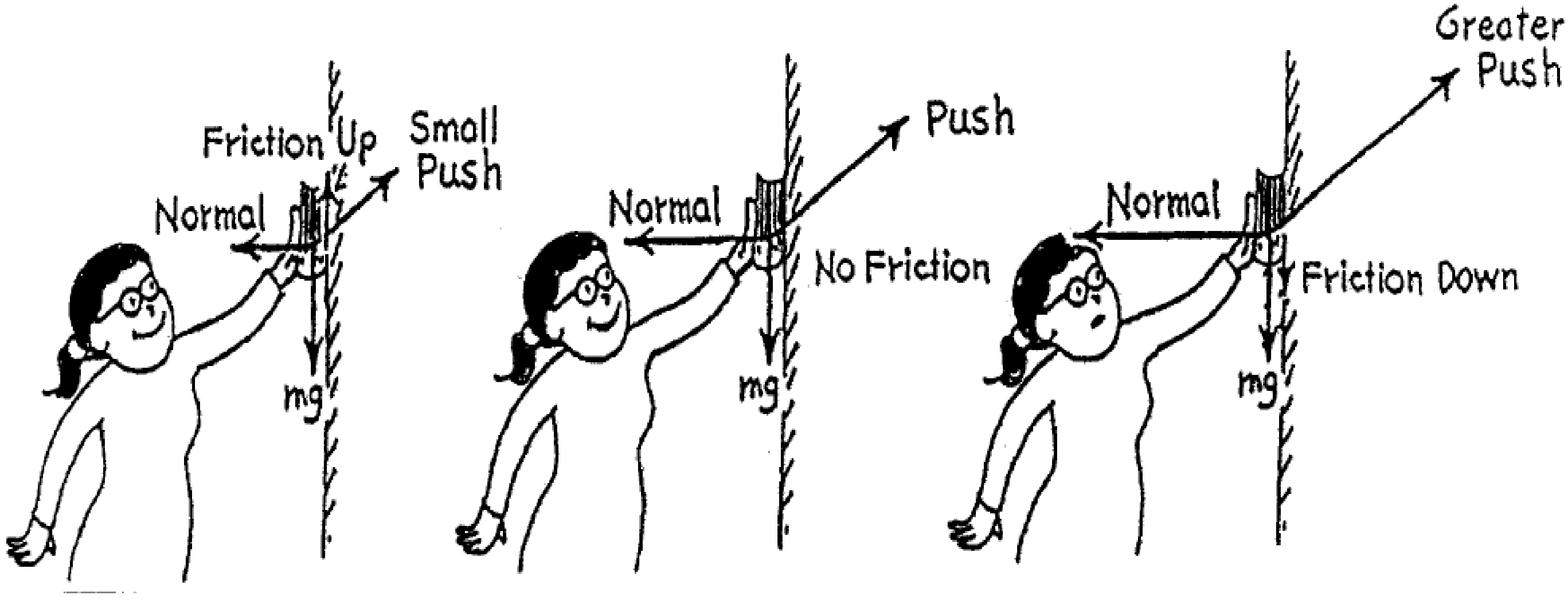
She holds the book stationary against the wall as shown. Friction on the book by the wall acts

1. upward.
2. downward.
3. can’t say.

Hint: first, draw a sketch showing the forces acting on the book. These should sum to the net force on the book - what should this net force be?

Answer: 3. can’t say

If she barely pushes the book so that the vertical component of her push is less than the book’s weight, then friction acts upward to keep the book stationary. If she pushes so that the vertical component of her push equals the book’s weight, then there’s zero wall friction on the book. If she pushes harder so that the vertical component of her push exceeds the book’s weight, then friction acts downward. So unless we know how the vertical component of her push compares with the weight of the book, we can’t specify the direction of friction between the book and the wall.



The normal force that acts on a block of ice that slides on a ramp

- is equal to *mg* at all angles.
- gets progressively less as the slope of the ramp increases.
- becomes greatest when the ramp is vertical.
- None of the above.

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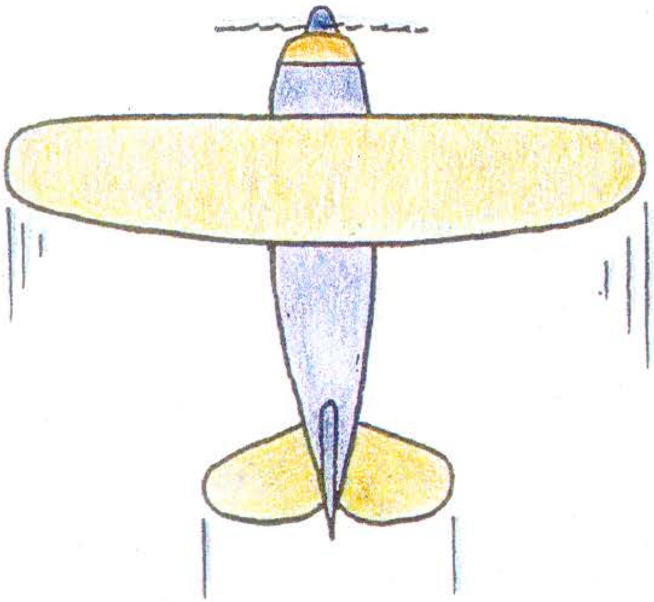
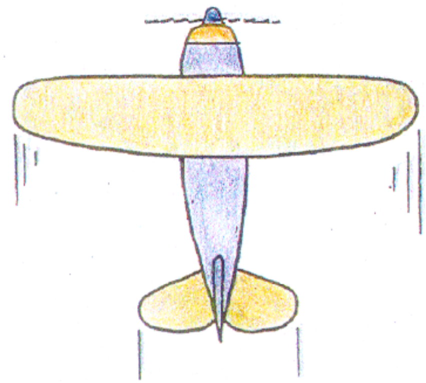


The speed of an airplane relative to the ground is affected by wind. When an airplane flies in the direction of a wind (tailwind), it has a greater groundspeed. When an airplane flies directly into a wind (headwind), it has a smaller groundspeed.

Suppose an airplane is blown off-course by a 90-degree crosswind (keeping the nose pointing in a direction perpendicular to the wind direction).

Will its groundspeed be more, less, or the same as in still air?



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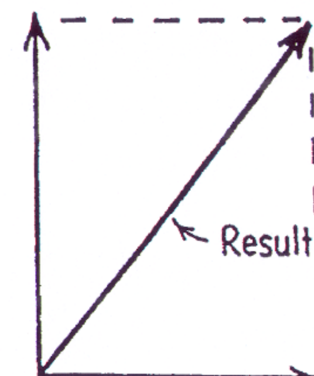
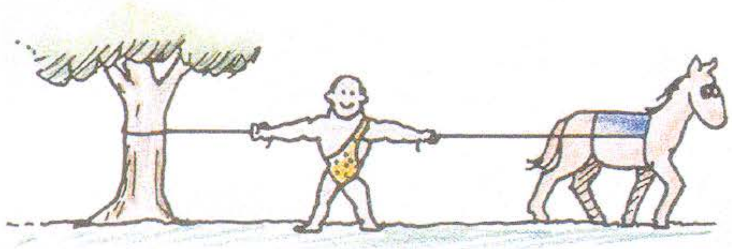
Suppose an airplane is blown off-course by a 90-degree crosswind (keeping the nose pointing in a direction perpendicular to the wind direction).
Will its groundspeed be more, less, or the same as in still air?

Answer: More

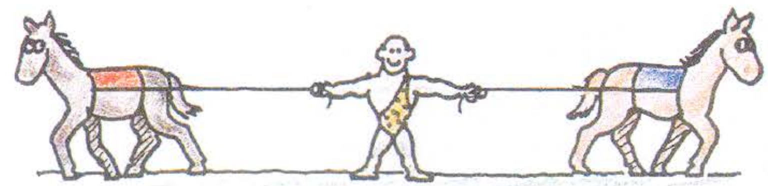
When directions as well as magnitudes of speeds are considered, we're into vectors. The resulting speed can be found by finding the resultant velocity via vector rules. The diagram shows a sample vector that represents the magnitude and direction of the air speed, and another that represents the velocity of wind speed. The resultant is the diagonal of the parallelogram so formed. In this case, the parallelogram is a rectangle. The Pythagorean Theorem ($c^2 = a^2 + b^2$) gives the magnitude of the resultant. The angle can be found with a protractor, or a bit of trigonometry.

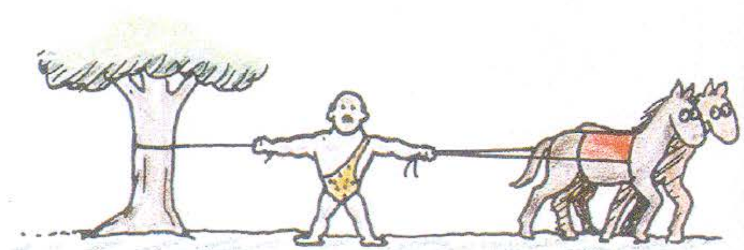


NEXT-TIME QUESTION



The strong man can withstand the tension forces exerted by the pair of ropes—one tied to a tree and the other to a horse. No problem. Compare the tension he experiences in two other situations shown to the right—horse and horse, and a tree and two horses.





Hewitt Drew it!