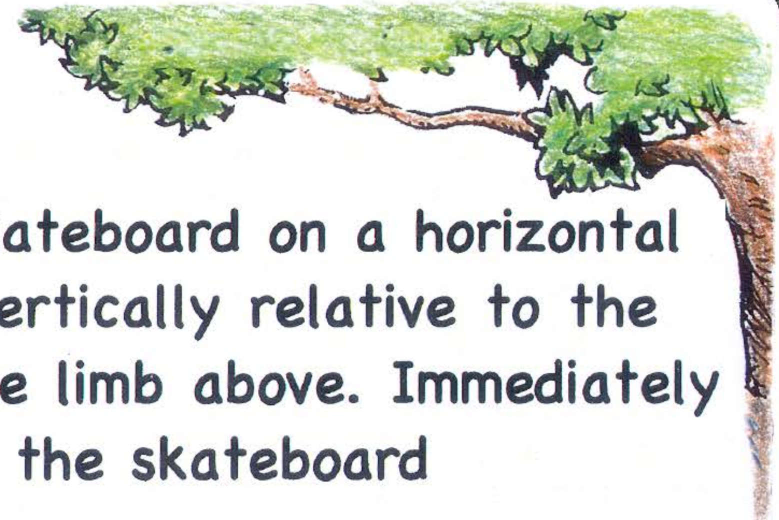
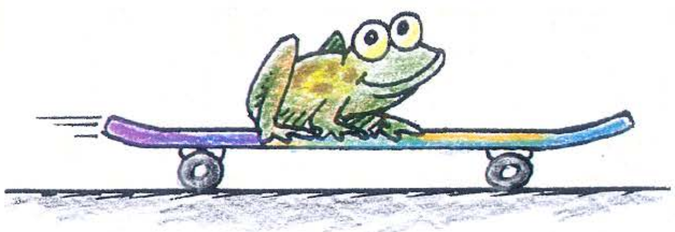
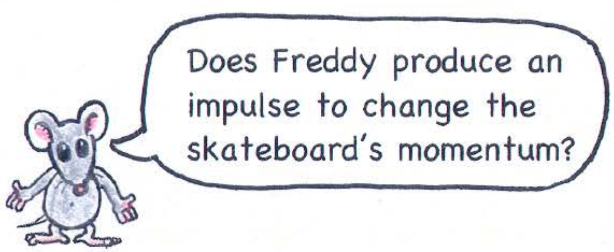
Next-Time Question



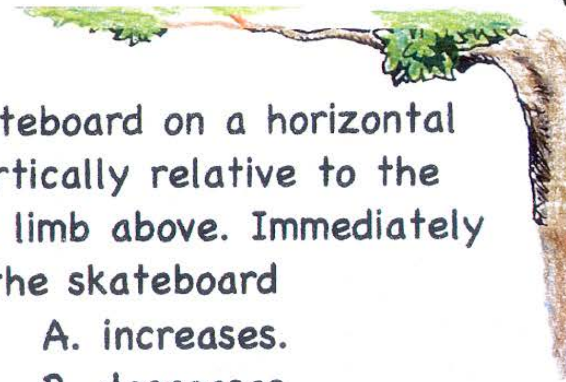
Freddy the frog rides on a skateboard on a horizontal surface. Freddy then jumps vertically relative to the board and catches onto a tree limb above. Immediately after the jump, the speed of the skateboard

A. increases.
B. decreases.
C. remains unchanged.





Next-Time Question



Freddy the frog rides on a skateboard on a horizontal surface. Freddy then jumps vertically relative to the board and catches onto a tree limb above. Immediately after the jump, the speed of the skateboard

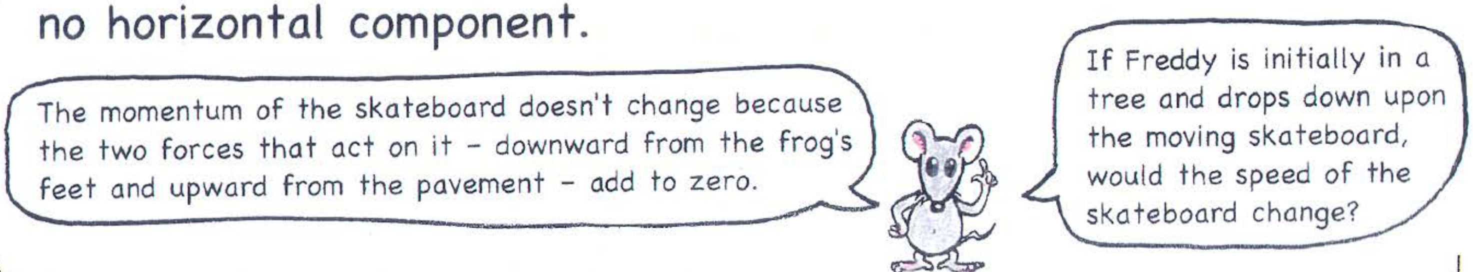
A. increases.

B. decreases.

C. remains unchanged.

Answer C.

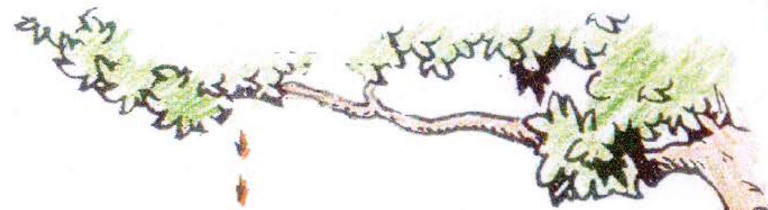
If Freddy had jumped in a forward direction relative to the skateboard, it would slow. If he had jumped backward relative to the board, the skateboard would gain speed. In both cases reaction to friction of his feet on the board would produce a horizontal impulse. Jumping vertically relative to the board, however, doesn't change the speed of the board since the force Freddy exerts on the board has no horizontal component.



Hewitt Drew it!

NEXT-TIME QUESTION

CONCEPTUAL PHYSICS



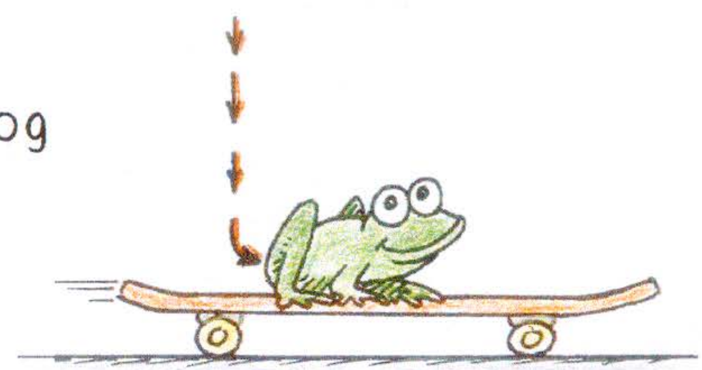
A massive frog drops vertically from a tree branch onto a skateboard that moves horizontally below. When the frog lands, the skateboard slows, consistent with the conservation of momentum. The *impulse* that slows the skateboard is

a) the friction force of the frog's feet acting backward on the skateboard × time during which the speed changes.

b) equal and opposite to the impulse that brings the frog up to speed.

c) Both of these.

d) Neither of these.



Hewitt Drew it!

NEXT-TIME QUESTION

CONCEPTUAL Physics

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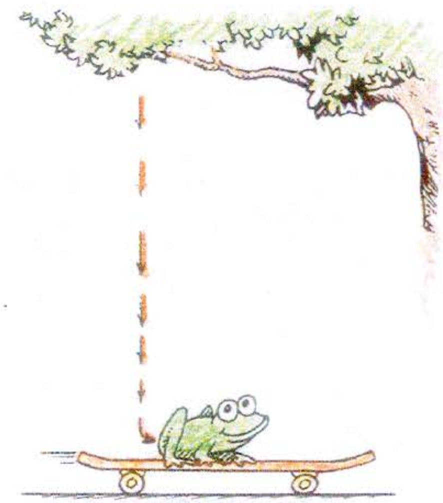


a) the friction force of the frog's feet acting backward on the skateboard × time during which the speed changes.
b) equal and opposite to the impulse that brings the frog up to speed.
c) Both of these.
d) Neither of these.

Answer: c

When the frog lands, a force of friction keeps it on the skateboard (a slippery surface wouldn't provide a ride). The impulse that reduces the momentum of the skateboard is the friction force of the frog's feet acting backwards on the skateboard × time during which the speed changes. The equal and opposite friction force of the skateboard on the frog's feet × the same time provides the forward impulse on the frog to bring it up to speed.

The net horizontal momentum of the (frog + skateboard) system is the same before and after the frog lands — because no *external* friction forces act (such as between the ground and the skateboard).

Hewitt Drew it!

What is Energy?

1. A state of mind

2. How you feel when you got out of bed in the morning

3. The capacity to do work

Reminders and Notices:

1st Exam **Feb 28**; review Feb 21 and some exam content posted on website

http://www.hunter.cuny.edu/physics/courses/physics100/physics-100

Chapter 7: Energy

Energy is a central concept in all of science. We will discuss how energy appears in different forms, but cannot be created or destroyed. Some forms are more useful than others in the sense of doing "work"….

Before getting into this, a little demo:

Hold pendulum bob at tip of nose and release.
It will never hit my nose on swinging back!

"Energy of position" ⟷ "energy of motion"

potential energy ↗ kinetic energy ↖

As time goes on, pendulum motion decays: its energy ⟶ heat, in air, and string…

Pendulum movie

Let’s start with closely related concept: Work

Work = force x distance

$$W = Fd$$

(c.f. Impulse, last class, which was force x time. A different measure of the “effectiveness” of the force)

Note this may differ from everyday notion of what work is!

Eg. Weight-lifting.

If I lift a weight up above my head, I do work: I exert a force, moving the weight a distance = height. Lifting it twice as high, I do twice as much work.

But if I am just holding the weight up above my head, I do zero work on the weight, as it is not moved. (I get tired due to work done on my muscles contracting and expanding, but no work is done on the weight)

Eg. Pushing on a wall, you may expend energy, but do no work on the wall if it doesn’t move.

Power

- Asks how fast is the work done

  i.e.

$$\text{Power} = \frac{\text{Work done}}{\text{time interval}}$$

Eg. A tank of fuel can do a certain fixed amount of work, but the power produced when we burn it can be any amount, depending on how fast it is burned. It can run one small machine for longer time than a larger machine.

Units:

Work = Fd, so units are Newton x meter = Joule, J

1 J = 1 N.m

Common for biological activity and food, is 1000 J = 1 kJ

Power = Work/t, so units are Joule per second = Watt, W

1 kW = 1000 W and 1 MW = 1 000 000 W

Eg. About 1 W of power is needed in vertically lifting a quarter-pound hamburger one meter in one second. See soon for how we got this…

Mechanical Energy

- When work is done on an object, energy is transferred to that object. This energy is what enables that object to then do work itself.

Mechanical energy = potential energy + kinetic energy

Energy due to relative position of interacting bodies (potential energy)

Energy due to motion (kinetic energy)

Potential Energy (PE)

- A "stored energy" due to the configuration of the system (i.e. position of objects). System then has the "potential" to do work.

Egs. - A stretched or compressed spring, or rubber band – if attach an object on the end, it can move that object, so can do work on it.

- Chemical energy in fuels, food etc, due to positions of the constituent atoms. When these atoms are rearranged (chemical process), energy becomes available. Or in batteries…

Potential Energy continued…

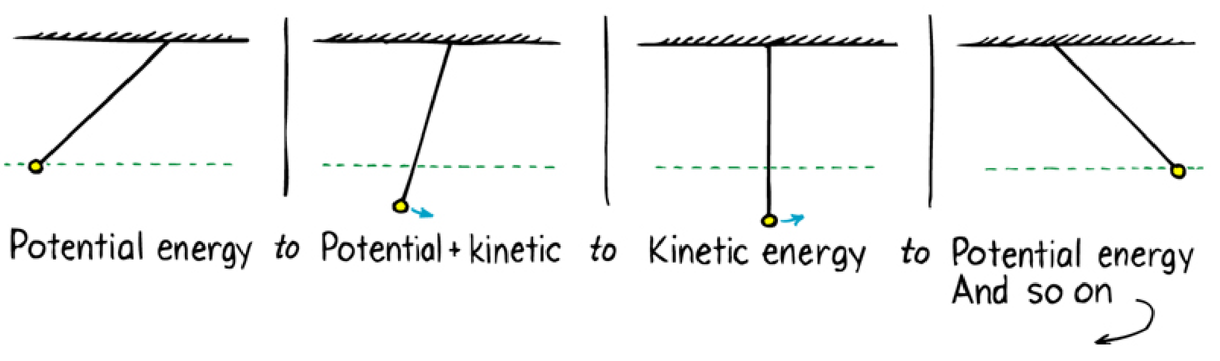
- An important example: **gravitational potential energy**

Work is required to raise objects against Earth's gravity – this work is stored as gravitational PE.

Eg. In some hydroelectric power plants, water is raised from a lower reservoir up to a higher one – so to a state of higher grav. PE. When electric energy is in demand, it is then released from high, PE transforms to motional (kinetic) energy and then electrical energy.

Eg. Pendulum: when pull to one side, you are raising it against gravity, exerting a force and doing work on it, giving it grav. PE:

Pendulum Interactive



- How much gravitational PE is stored when object is raised a height h ?

Must equal the amount of work done in lifting it.:

$W = F.d$, where $F = mg$, and $d = h$

i.e. <u>gravitational PE = *mgh*</u>

Eg. How much gravitational potential energy does a quarter-pound hamburger vertically raised 1 m have?

grav. PE = mgh = ¼ (4.4N)(1m) = 1.1 J

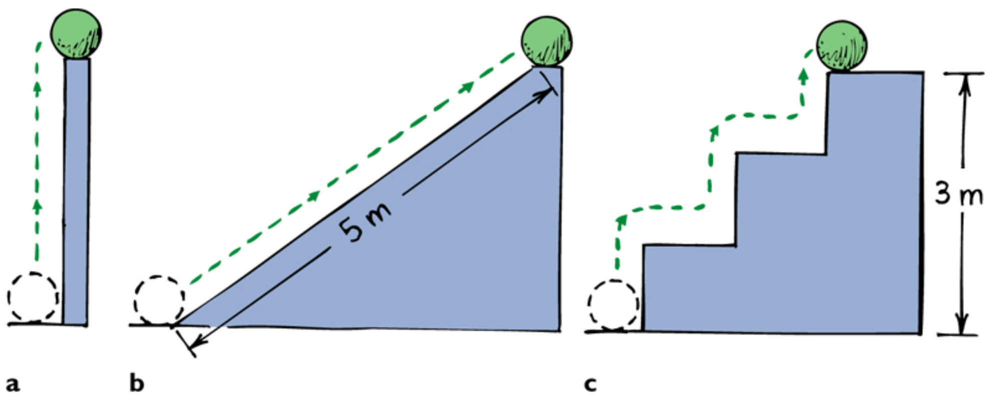
(recall 1-lb is about 4.4 N)

So this is the work done in vertically lifting it 1m, and hence the power needed to do this in 1s is Power = W/t = 1.1 J/1s = 1.1 W

(c.f earlier statement)

$PE = mgh$

- **Important note!** It doesn't matter *how* the raise was done*:*



The potential energy of the ball is the same at the top, in all three cases, because the work done,

$W = Fd = mgh$

is the same whether lifted, pushed, or hopped up. (We are neglecting friction, as assuming no force needed to move it horizontally)

Another important note! *h* is defined relative to some reference level. Often we take that reference to be the ground. But we don't need to – and if we don't, the #'s we get for PE are different.

That's ok – PE doesn't have absolute meaning. Only ***changes*** in it have meaning. When PE changes, the energy gets transformed to a different form (esp. motional) – the change has physically measurable consequences.

Kinetic Energy (KE)

- Is the energy of motion:

KE = ½ mass x speed x speed

i.e. $KE = \frac{1}{2} m v^2$

- KE depends on the reference frame in which it is measured (like the speed).

e.g When you are sleeping, relative to your bed, you have zero KE.

But relative to the sun, you have KE = ½ (your mass) $(107\ 000\ \text{km/h})^2$

Work-Energy Theorem

- When an object speeds up, its gain in KE comes from the work done on it:

$$\text{Work} = \Delta\ \text{KE}$$

Net work (Work) — *Can be an increase (+) or decrease (-) in speed* (Δ KE)

Eg. Pushing a table from rest. Its gain in KE = Fnet x distance, where

Fnet = your force – friction. Only part of the work you do goes into KE of table, the rest goes into heat.

Questions

(1) A father pushes his child on a sled on level ice, a distance 5 m from rest, giving a final speed of 2 m/s. If the mass of the child and sled is 30 kg, how much work did he do?

$W = \Delta KE = ½\, m\, v^2 = ½\, (30\text{ kg})(2)^2 = \underline{60\text{ J}}$

(2) What is the average force he exerted on the child?

W = $F.d$ = 60 J, and d = 5 m, so F = 60/5 = $\underline{12\text{ N}}$

More Questions

(3) Consider a 1000-kg car going at 90 km/h. When the driver slams on the brakes, the road does work on the car through a backward-directed friction force. How much work must this friction force do in order to stop the car?

$W = \Delta\ KE = 0 - \frac{1}{2}\ m\ v^2 = -\ \frac{1}{2}\ (1000\ kg)\ (90\ km/h)^2\ (1000\ m/3600\ s)^2$

$= -312500\ J = -312.5\ kJ$

So <u>W = 312.5 kJ</u>

(the – sign just means the work leads to a decrease in KE)

(4) How much more distance do you need to stop when going at 90 km/h compared to 45 km/h ? (Note that the frictional force the road exerts does not depend on speed).

$W = F\ d = \Delta\ KE$, where F is the friction force.

Since, for speeds twice as large, the KE is four times as large, this means the stopping distance is also <u>four times as large</u>.

More Questions

When you pay your monthly electricity bill, what are you paying for, Energy or Power?

Energy! For electricity this is normally expressed as kW-hr
1 kW-hr = 1000 Joules/s x 3600 s/hr = 3.6 million Joules

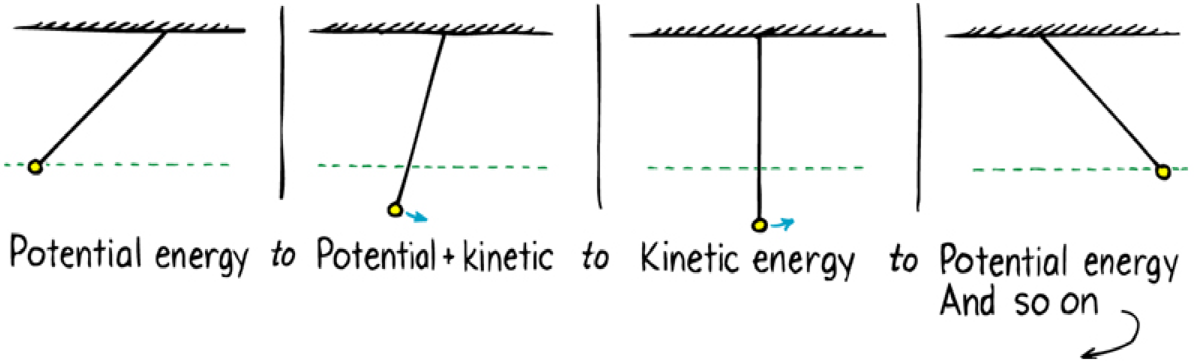
Conservation of Energy Law

- Kinetic and potential are two fundamental forms of energy; another is radiation, like light. Other (less fundamental) forms of energy: chemical, nuclear, sound…

- **Energy cannot be created or destroyed; it may be transformed from one form into another, but the total amount of energy never changes.**

With anything, energy is recycled between different forms.

eg. Earlier pendulum example



Eventually, pendulum stops, due to energy transformed to heat in air and string…

Another example

Eg. Dropping down from a pole. As

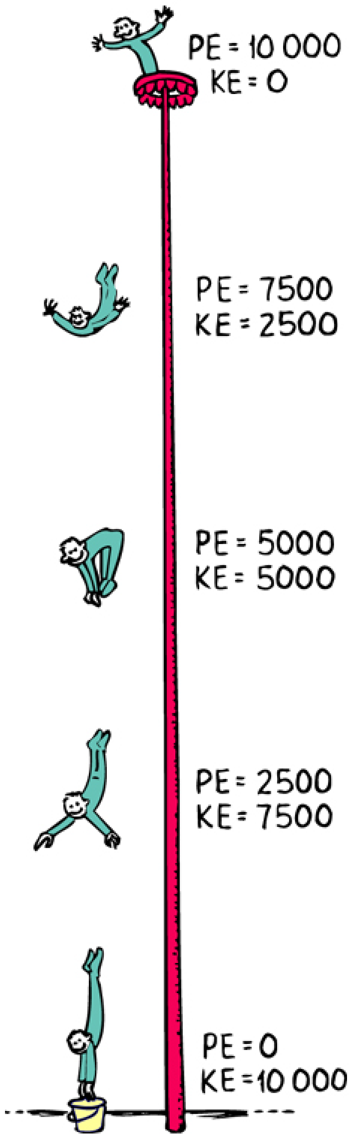
he dives, PE becomes KE. Always total energy constant.

If accounted for air resistance, then how would the numbers change?

In presence of air, some energy gets transformed to heat (which is random motion of the air molecules). Total energy at any height would be PE + KE + heat, so at a given height, the KE would be less than in vacuum.

What happens when he hits the ground?

Just before he hits ground, he has large KE (large speed). This gets transformed into heat energy of his hands and the ground on impact, sound, and energy associated with deformation .



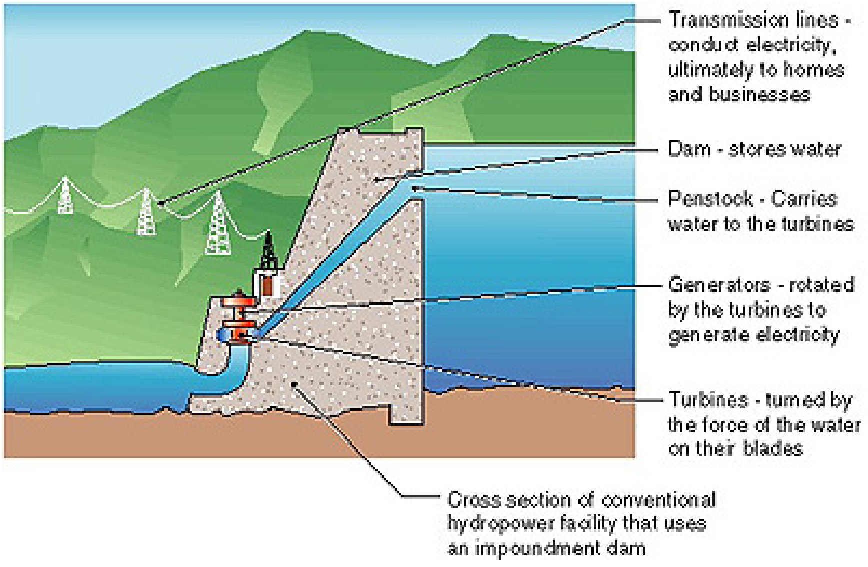
Ball Up & Down

And another example: sun and then to earth..

- In the core of the sun, *thermonuclear fusion* occurs: due to gravity and very high temperature, hydrogen nuclei fuse together making helium nuclei, releasing lots of radiant energy. i.e potential + kinetic radiant energy.

A small part of this radiation reaches the earth → stored as chemical energy in plants, coal etc. → kinetic energy, → electric energy, etc…

Recall hydroelectric power earlier : in fact sun's radiant energy → gravitational potential energy of water as it evaporates it from oceans etc, some may return to earth trapped in a dam at high elevation → then be transformed to kinetic as it falls →electric energy powering our homes…



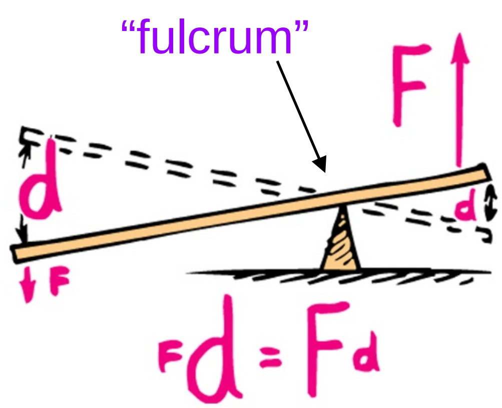
Machines

- Something that multiplies forces, and/or changes their direction.
- Main principle: energy is conserved,

Work input = work output

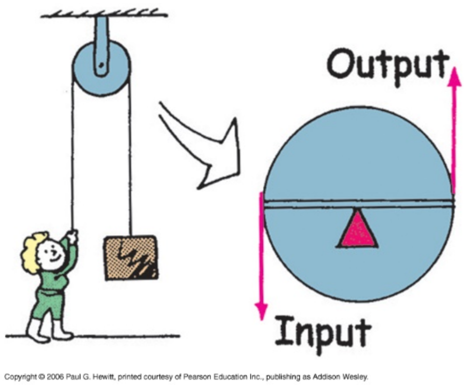
(if we can neglect friction)

Eg. Lever : put load close to fulcrum. Then small input force (down on the left) yields a large output force on the load (up on the right). Input force moves over large distance, load is lifted up short distance (*W* = *Fd* same for output and input)

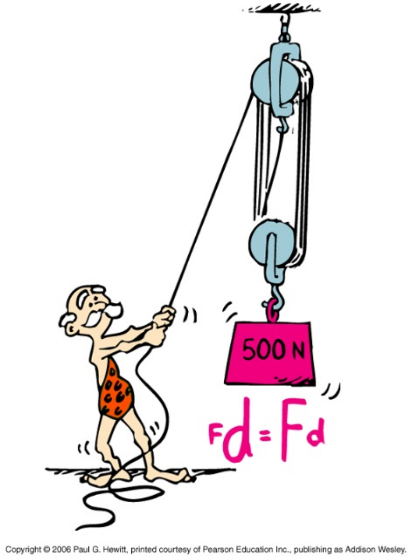


- Eg. Pulley –same principle as lever

Here, it just reverses direction of input force (no multiplication)



- Here ("block and tackle" pulley system), man pulls with a force of 50 N, but can lift 500 N weight up: he moves the rope 10x the distance that the weight moves vertically up.



Note: Always, energy is conserved – machines just trade force for distance, but so that the product *Fd* is the same input as output.

Pulleys Interactive

Efficiency

In reality, Work output < Work input, because some energy is dissipated as heat – i.e. thermal energy, which is random molecular kinetic energy, not useful.

Define

$$\text{Efficiency} = \frac{\text{useful energy output}}{\text{total energy input}}$$

Eg. Pulley system – much of the input energy goes into thermal energy from friction, with ropes and pulleys turning and rubbing about the axles.

Say you put in 100 J of work but the output is only 40 J. Then efficiency = 40%.

Comparing kinetic energy and momentum

- Both are a measure of motion, and both are bigger when things go faster, and when things are heavier.

- Differences:

  - momentum is a vector, with direction, whereas KE is a scalar, always greater or equal to 0.

  - Also, momentum is always conserved in a collision, whereas KE is not

  - Momentum scales with speed as v, however KE scales as v^2

  - The change in momentum is determined by impulse imparted on the object, whereas change in KE is determined by the work done on it.

• Example of your standing on a log while a friend tries to knock you off by throwing balls to you. Should you try to catch the ball, or let it bounce off you, in order to try to stay on the log?

If you catch the ball, ball changes its mom. from *mv* to *0.*

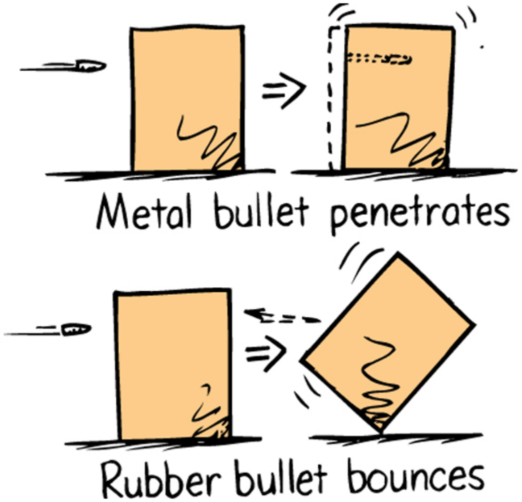
Whereas, if you let it bounce off you, ball reverses direction of momentum, so change in momentum is twice as large.

So it's better to try to catch it, as there is less change.

- This example has similar physics to one in your book – metal vs rubber bullet on a wooden block (or a person ☹). The rubber bullet tends to bounce off, whereas the metal bullet penetrates.

For rubber bullet, the change in mom. and the impulse, is greater: if it bounces back elastically, the change is twice that of the metal bullet.

Because it does not penetrate, it does little damage – very little (none if elastic) change in its KE. Whereas the metal bullet comes to rest and all its KE becomes heat – so damage…



Sources of energy

- Except for nuclear, and geothermal power, source of our energy is ultimately the **sun**: eg. Gas, wood, coal, petroleum combustion – all these come from plants, which used sun's radiant energy in photosynthesis.

Generates pollutants, and CO_2, environmentally bad

Also, sun is responsible for energy in photovoltaic cells in solar-powered panels, or calculators, and in generating electricity (recall earlier, hydropower)

Wind energy/power, in a sense comes from sun too, since wind is due to unequal warming of Earth's surface. Harder for us to control, so only used supplementally to fossil fuels…Unless we have big batteries…

- **Nuclear energy/power** - uranium, plutonium, very powerful. Fears of radiation leakage and long term storage of radioactive waste have limited its growth.

Note that the earth's core is so hot because of naturally occurring nuclear radioactive decay!

- **Geothermal** energy/power – from underground reservoirs of hot water, so often in volcanic lands.

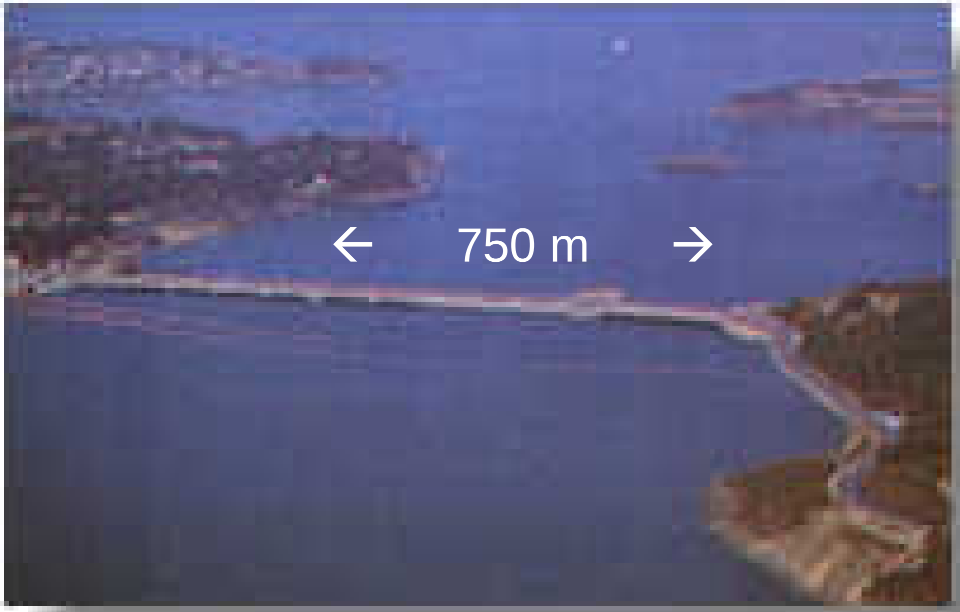
10 m.

World's largest hydroelectric plant (until China's 3-Gorges), converts potential energy of water to K.E., and then electrical energy(Ch.25); Recall, form of solar energy (why?)

Control room simulator (!) at Indian Point nuclear power plant, provides 2 GW to NYC and lower Hudson Valley. Converts P.E stored in ^{235}U nucleus (Ch. 33,34) into heat and then rotational K.E. (Ch.8), and then electricity Ch.25).

Ravenswood gas-fired electric power plant, LIC, NY
L: steam turbine; R: control room

Windfarm –converts K.E. to electricity (another form of solar energy (why?)



The largest tidal power station in the world (and the only one in Europe) is in the Rance estuary in northern France. It was built in 1967 and produces 240 MWe

www1.eere.energy.gov/

Concentrator: solar furnace
→ Heat engine; high T water splitting for H_2

Direct (flat panel) PV

Home use

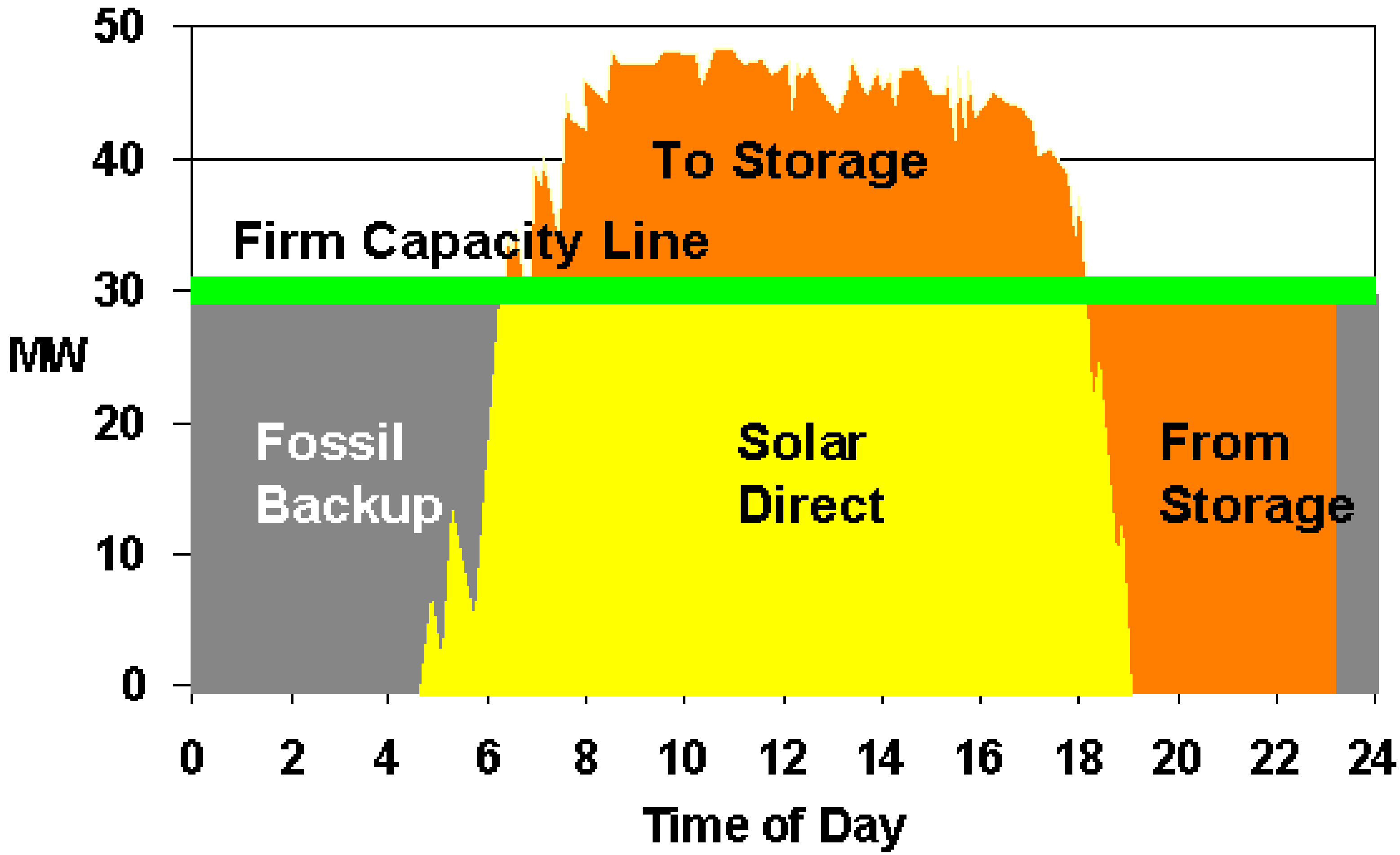
Space power (not too far from Sun)

Centralized electricity or H_2 generation (e.g. Southwest)?

Solar Land Area Requirements

http://nsl.caltech.edu

http://www.powerfromthesun.net/chapter1/Chapter1.htm



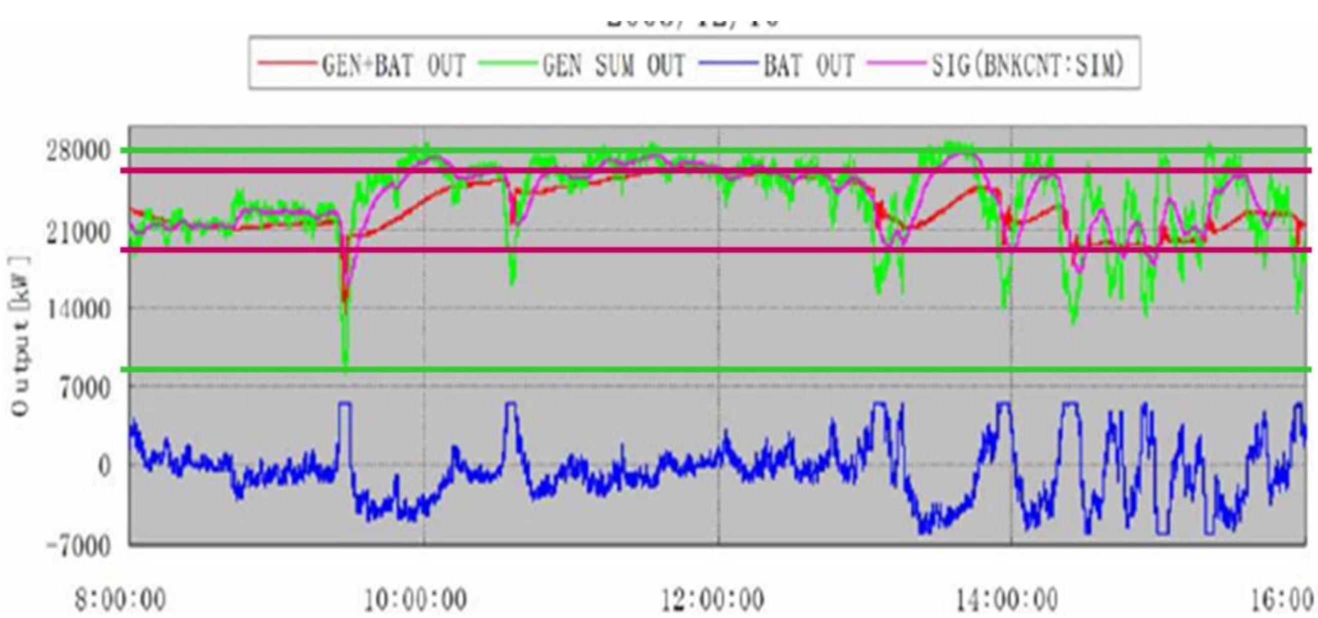
Punchline: **Storage!**

Frequency Regulation (s)

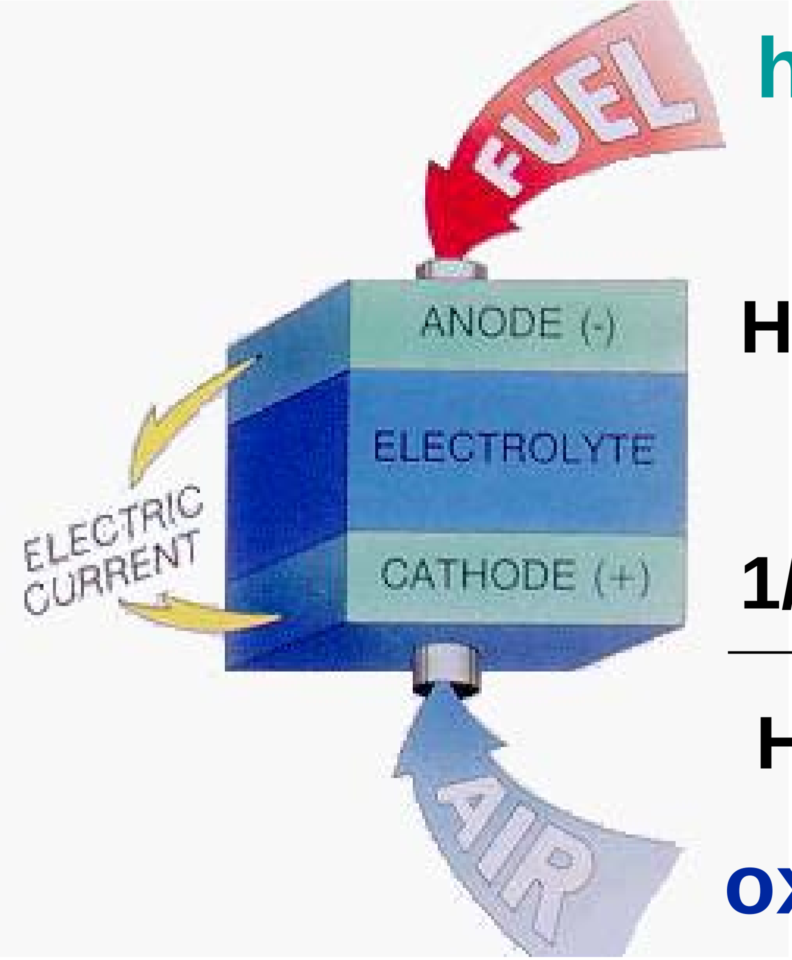
Load leveling (Capacity Firming) (s – m – h)

Energy Storage - Wind

32MW farm using 4MW 1.5hour VRB ESS – Sapporo-Japan



How does PEM fuel cell work?



hydrogen

$H_2 \text{ --> } 2 H^+ + 2 e^-$

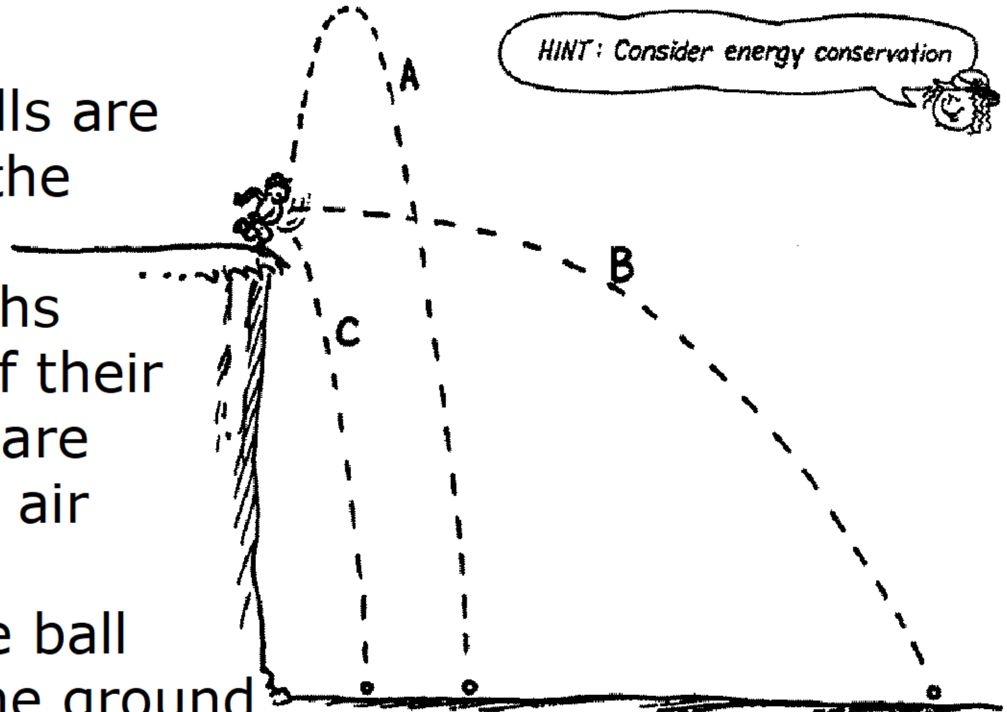
$1/2 O_2 + 2 H^+ + 2 e^- \text{ --> } H_2O$

$H_2 + 1/2 O_2 \text{ --> } H_2O$

oxygen

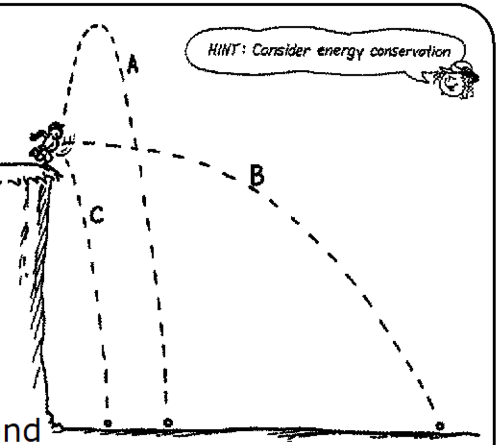
T.A. Zawodzinski, Jr., Los Alamos NL and Case Western U.

Three baseballs are thrown from the top of the cliff along paths A, B, and C. If their initial speeds are the same and air resistance is negligible, the ball that strikes the ground below with the greatest speed will follow path



1. A.
2. B.
3. C.
4. Either A or C.
5. All strike with the same speed.

Answer: all strike with same speed.

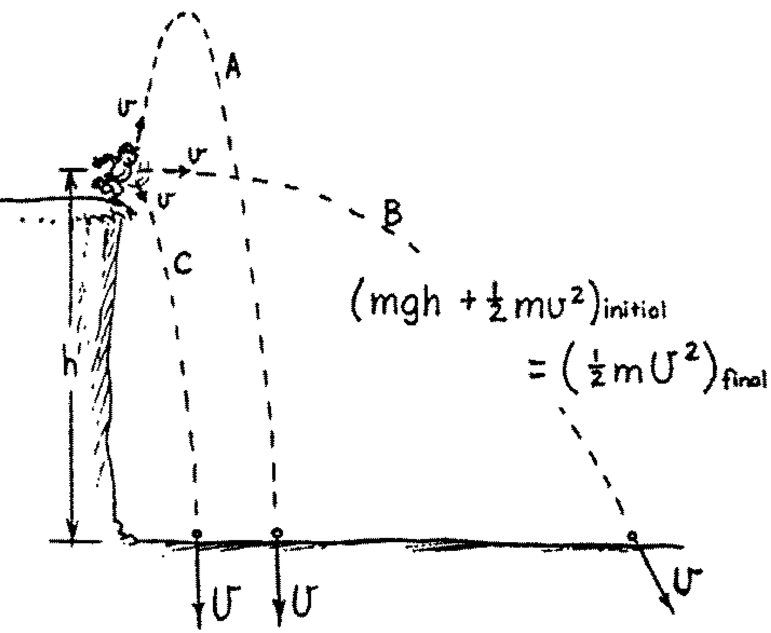


Three baseballs are thrown from the top of the cliff along paths A, B, and C. If their initial speeds are the same and air resistance is negligible, the ball that strikes the ground below with the greatest speed will follow path

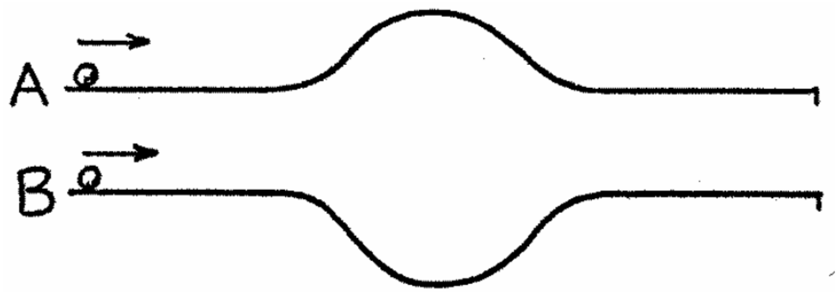
1. A. 2. B. 3. C. 4. Either A or C.

✔ **5. All strike with the same speed.**

The speed of impact for each ball is the same. With respect to the ground below, the initial kinetic + potential energy of each ball is the same. This amount of energy becomes the kinetic energy at impact. So for equal masses, equal kinetic energies means the same speed.



NEXT TIME QUESTION



Two smooth tracks of equal length have "bumps"—A up, and B down, both of the same curvature. If the initial speed = 2 m/s, and the speed of the ball at the bottom of the curve on Track B is 3 m/s, then the speed of the ball at the top of the curve on Track A is

1. 1 m/s. 2. > 1 m/s. 3. < 1m/s.

NEXT-TIME QUESTION

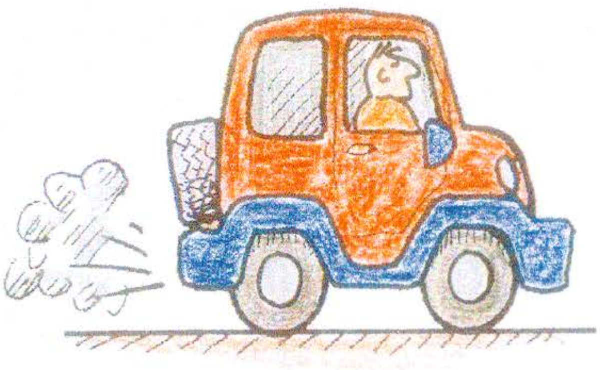
CONCEPTUAL Physics

A typical car weighs about 1.5 tons, and the weight of carbon in a gallon of gasoline is about 5 lb. The CO_2 that's emitted by a typical car in a year weighs

a) much less than the car.

b) about as much as the car.

c) much more than the car.



thanks to Art Hobson

Hewitt Drew it!