<u>Today: Chapter 7 -- Energy</u>

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”….

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 (d=0). (I get tired due to work done on my muscles contracting and expanding, but no work is done *on the weight)*

Work = Fd,

The force, in order to do work, has to be parallel to the distance

Units:

Newton x meter = Joule, J

1 J = 1 N.m

Clicker Question

This poor guy is pushing really hard on the wall but it won’t budge. What can you say is true?

A) He exerts a large force on the wall but does zero work on it.
B) He exerts zero force on the wall and does zero work on it.
C) He exerts a large force on the wall and does a large amount of work on it.
D) None of the above is true

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Answer: A
He exerts a large force on the wall but it does not. As the wall does not move there is no work done (W=F.d) on the wall.

Power

- Asks how fast is the work done

  i.e.

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

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.

Power = Work/t,

so units are Joule per second = Watt, W

1 kW = 1000 W

Eg. About 10 W of power is needed in vertically lifting a 1 kg box 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

Energy due to motion

Potential Energy (PE)

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

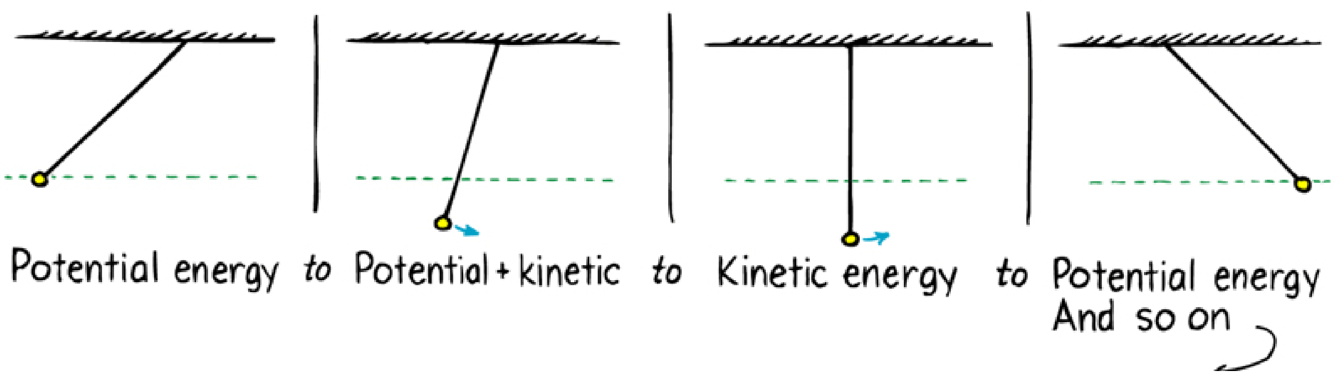
Egs. - A stretched or compressed spring, or rubber band – if attach an object on the end, it can move that object, so can do work on it.

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.

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



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

The work done by an external force to move an object of mass m a distance h is equal to the potential energy of the object-

$$W = F.d\ ,$$

$F = mg$, and $d = h$

gravitational PE = *mgh*

Eg. How much gravitational potential energy does a box of 1 kg vertically raised 1 m have?

PE = $mgh = (1\ kg)(10 m/s^2)(1\ m)$=10 J

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 = 10J/1s = 10 W

Clicker Question

A 1000-kg car and a 2000-kg car are hoisted up the same distance. Raising the more massive car requires

A) Less work
B) Twice as much work
C) Four times as much work
D) As much work
E) More than four times as much work

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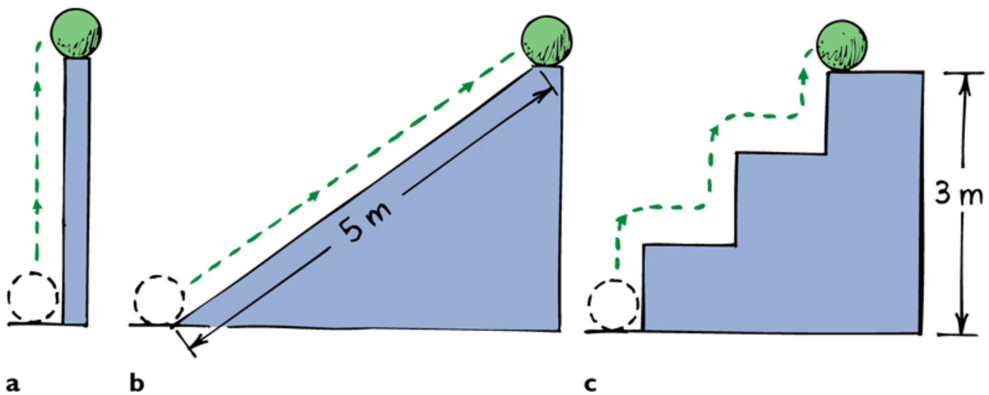
Answer: B.

Work done = gain in potential energy = mgh. So twice the mass means twice the PE, means twice the work

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 total work done,

$$W = Fd = mgh$$

is the same whether lifted, or hopped up. (This assumes no force needed to move it horizontally – so neglecting friction)

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

$$\mathbf{KE = \tfrac{1}{2}\, \boldsymbol{m}\, \boldsymbol{v}^2}$$

- 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 km/h)^2

Work-Energy Theorem

- The net work done on an object is equal to the change in the object's kinetic energy

$$\mathbf{W_{net} = \Delta\, KE}$$

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.

Clicker Question

Which has greater kinetic energy, an adult running at 3 mi/hr or a child of half the mass running at 6 mi/hr?

A) The adult

B) The child

C) Both have the same kinetic energy.

D) More information is needed about the distance traveled.

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Answer: B

KE = ½ mv^2, so for child, mass halved but v doubled means KE is doubled.

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 (neglecting friction). If the mass of the child and sled is 30 kg, how much work did he do?

$$W = \Delta KE = \tfrac{1}{2}\, m\, v^2 = \tfrac{1}{2}\,(30\text{ kg})(2)^2 = \underline{60\text{ J}}$$

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

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?

$W = \Delta\ KE = 0 - ½\ m\ v^2 = -\ ½\ (1000\ kg)\ (90\ km/h)^2\ (1000\ m/3600\ s)^2$

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

So $\underline{W = 312.5\ kJ}$

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

Clicker Question

Stopping Distance:

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

A) Half the distance
B) The same
C) Twice the distance
D) Four times the distance
E) Need more information in the problem

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Answer: D

W = F d = Δ KE, where F is the friction force.

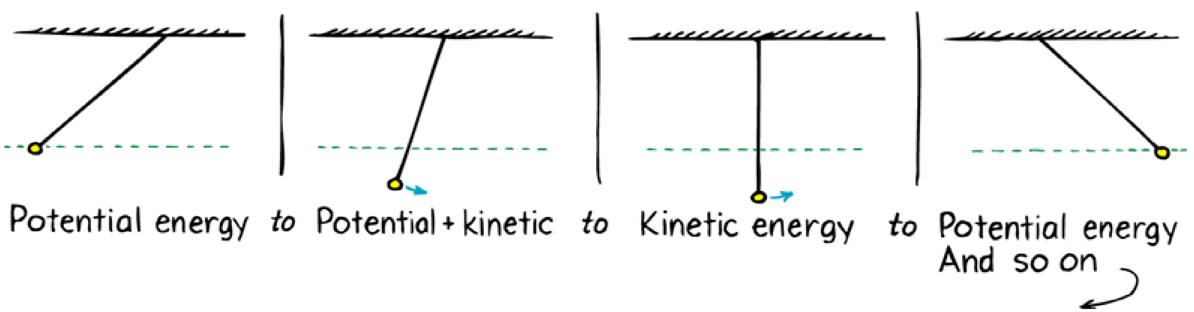
Since, for speeds twice as large, the KE is four times as large, this means the stopping distance is also <u>four times as large</u>.

Conservation of Energy Law

- Kinetic and potential are two fundamental forms of energy; another is radiation, like light. Other forms of energy: chemical, nuclear, sound…
- Note that work is a way of transferring energy from one form to another, but itself is not a form of energy.
- **Energy cannot be created or destroyed; it may be transformed from one form into another, but the total amount of energy never changes.**

Energy is recycled between different forms.

eg. Earlier pendulum example



Eventually, pendulum stops, due to energy transformed to heat

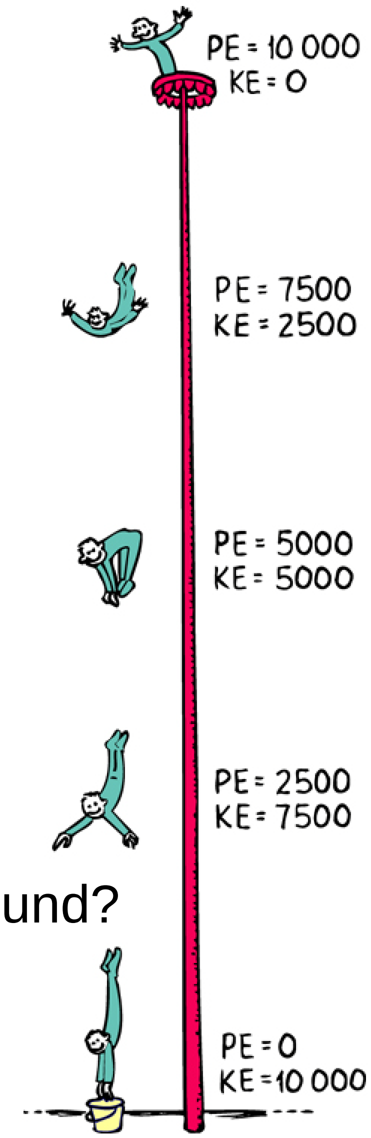
Another example

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. PE would be the same for same height.



• What happens to the energy 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

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Clicker Question

A marble is rolling down an incline, starting from rest at the top. At what point is its kinetic energy equal to its potential energy?

A) At the top
B) At the bottom
C) Halfway down
D) A quarter of the way down

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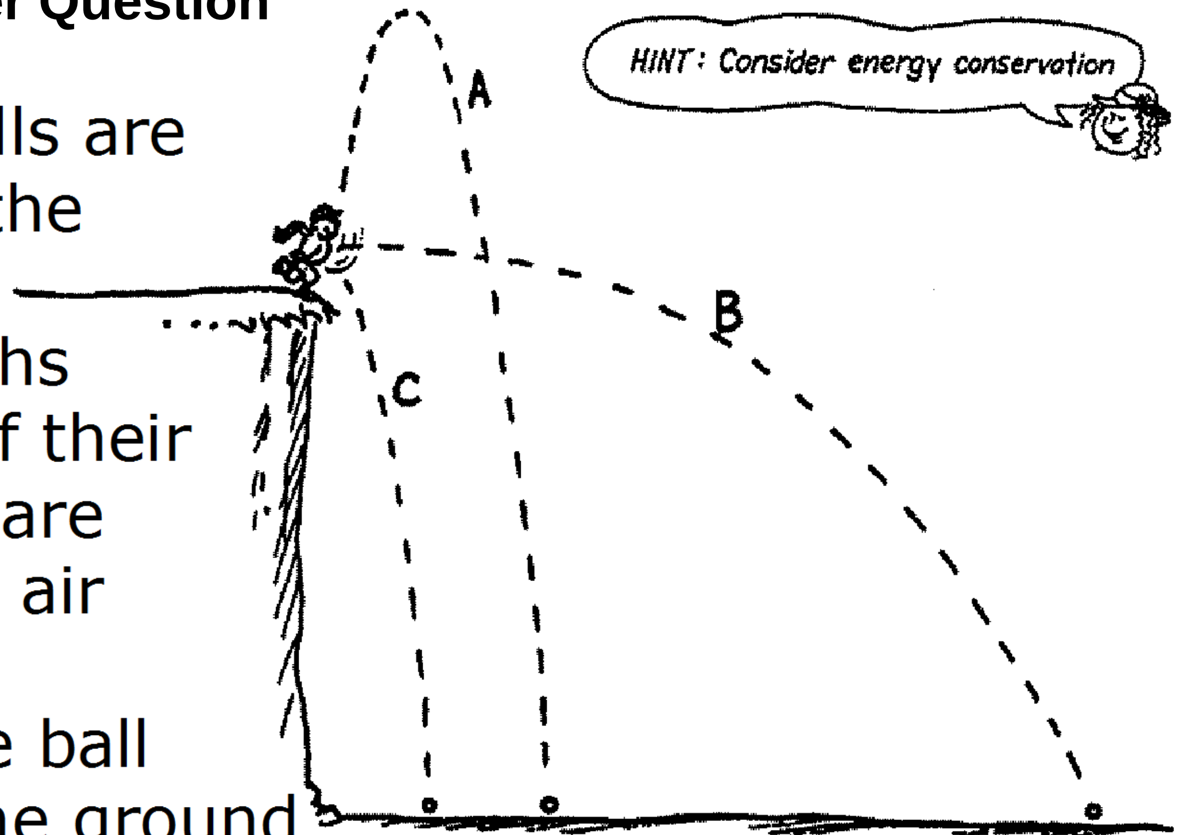
Answer: C

From energy conservation: at the top, zero KE and PE = mgh where h is the height of the incline. As it rolls, the marble loses PE which turns into KE, and it speeds up. At half the height of the incline, $h \rightarrow h/2$ so the PE is halved and, the other half of the PE has become KE.

Clicker Question



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.

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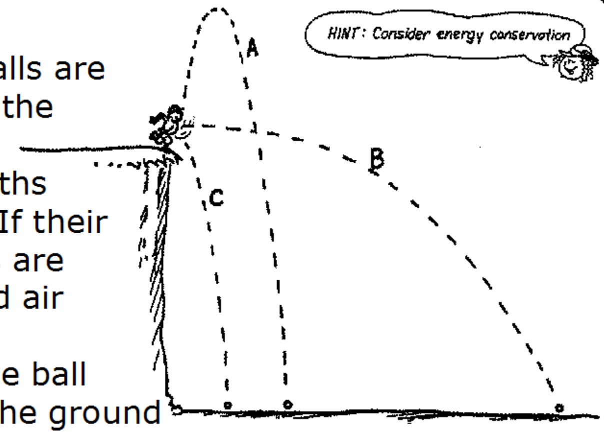

1. A. 2. B. 3. C. 4. Either A or C.

✔ **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.