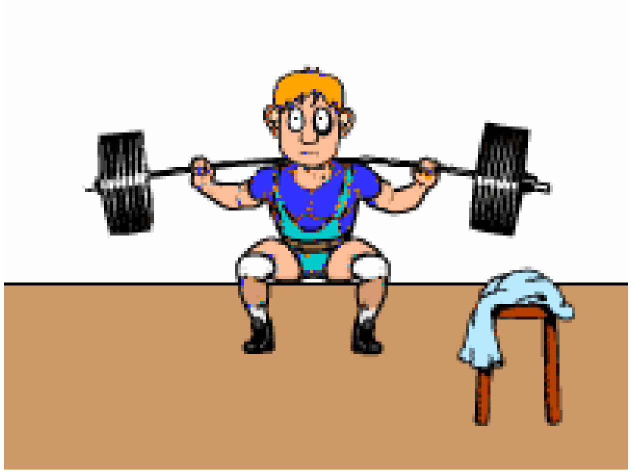
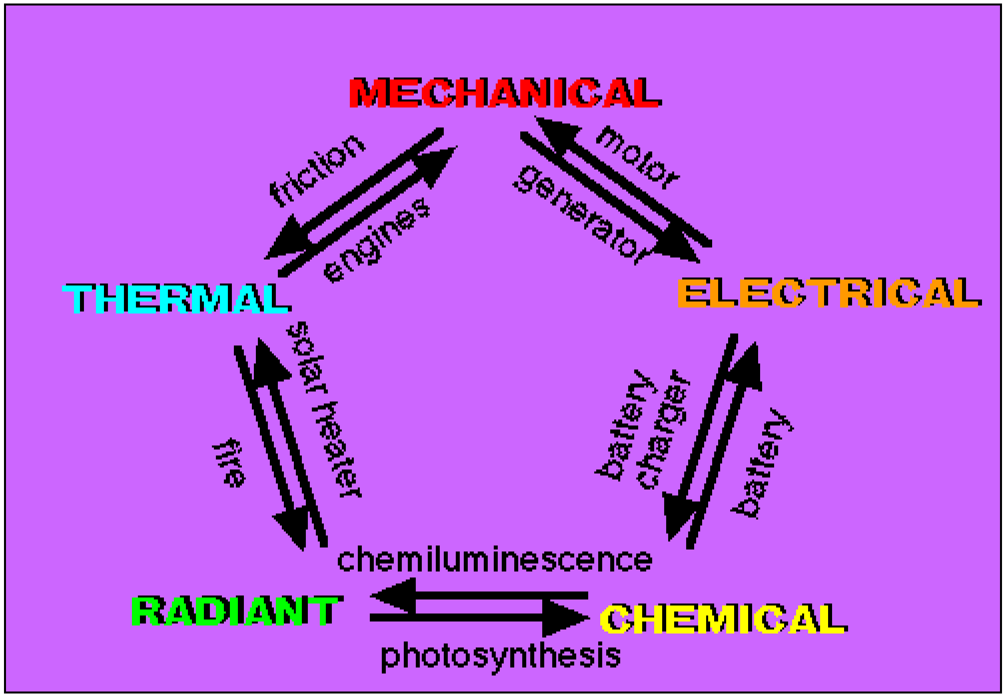
Work, Energy & Power

AP Physics B



There are many different TYPES of Energy.

- Energy is expressed in JOULES (J)
- 4.19 J = 1 calorie
- Energy can be expressed more specifically by using the term **WORK(W)**



Work = ***The Scalar Dot Product between Force and Displacement.*** So that means if you apply a force on an object and it covers a displacement you have supplied ENERGY or done WORK on that object.

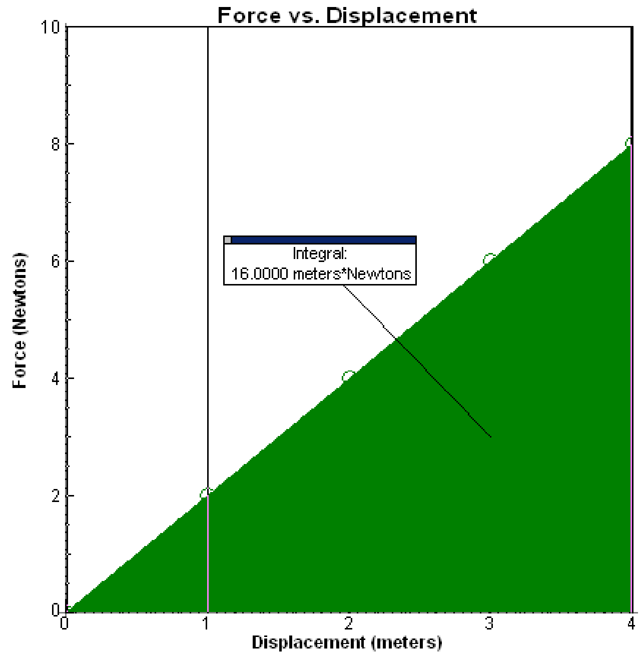
Scalar Dot Product?

$$W = \vec{F} \bullet \Delta\vec{x} \rightarrow \vec{F}\vec{x}\cos\theta$$

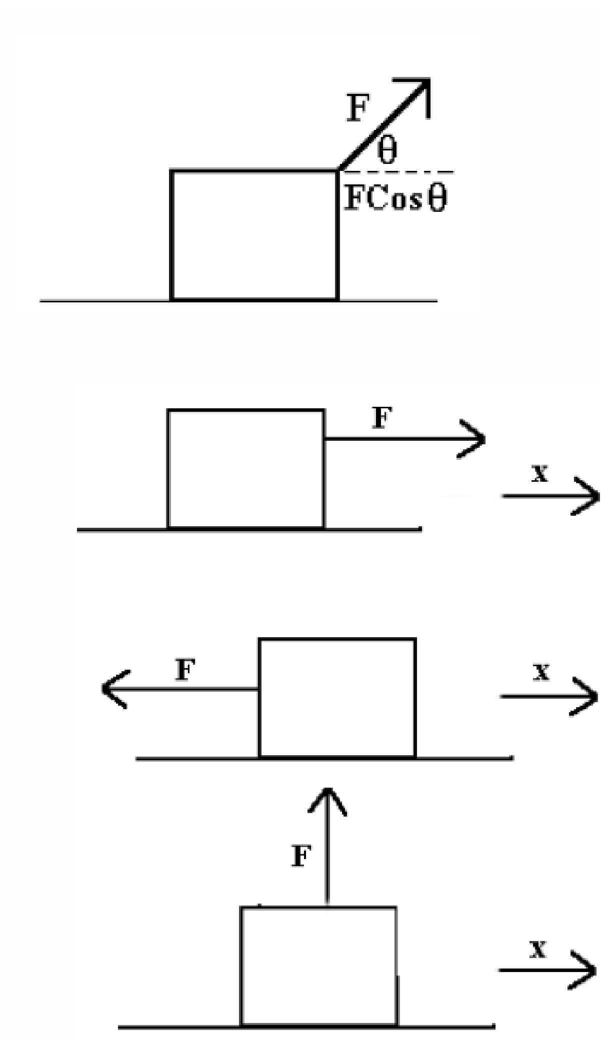
A product is obviously a result of multiplying 2 numbers. A scalar is a quantity with NO DIRECTION. So basically Work is found by multiplying the Force times the displacement and result is ENERGY, which has no direction associated with it.

W = Fx
Area = Base x Height

A dot product is basically a CONSTRAINT on the formula. In this case it means that F and x MUST be parallel. To ensure that they are parallel we add the cosine on the end.



Work



The VERTICAL component of the force DOES NOT cause the block to move the right. The energy imparted to the box is evident by its motion to the right. Therefore ONLY the HORIZONTAL COMPONENT of the force actually creates energy or WORK.

When the FORCE and DISPLACEMENT are in the SAME DIRECTION you get a POSITIVE WORK VALUE. The ANGLE between the force and displacement is ZERO degrees. **What happens when you put this in for the COSINE?**

When the FORCE and DISPLACEMENT are in the OPPOSITE direction, yet still on the same axis, you get a NEGATIVE WORK VALUE. **This negative doesn't mean the direction!!!!** IT simply means that the force and displacement oppose each other. The ANGLE between the force and displacement in this case is 180 degrees. **What happens when you put this in for the COSINE?**

When the FORCE and DISPLACEMENT are PERPENDICULAR, you get NO WORK!!! The ANGLE between the force and displacement in this case is 90 degrees. **What happens when you put this in for the COSINE?**

The Work Energy Theorem

Up to this point we have learned Kinematics and Newton's Laws. Let 's see what happens when we apply BOTH to our new formula for WORK!

1. **We will start by applying Newton's second law!**
2. **Using Kinematic #3!**
3. **An interesting term appears called KINETIC ENERGY or the ENERGY OF MOTION!**

$$K = \text{Kinetic Energy}$$

$$K = \frac{1}{2}mv^2$$

$$W = Fx \quad , F = ma$$

$$W = max$$

$$v^2 = v_o^2 + 2ax \rightarrow \frac{v^2 - v_o^2}{2} = ax$$

$$W = m(\frac{v^2 - v_o^2}{2})$$

$$W = \frac{1}{2}mv^2 - \frac{1}{2}mv_o^2 \rightarrow \Delta K$$

The Work Energy Theorem

And so what we really have is called the WORK-ENERGY THEOREM. It basically means that if we impart work to an object it will undergo a CHANGE in speed and thus a change in KINETIC ENERGY. Since both WORK and KINETIC ENERGY are expressed in JOULES, they are EQUIVALENT TERMS!

Work-Enegy Theorem

$$W = \Delta K, K = \frac{1}{2} mv^2$$

$$W = \frac{1}{2} mv^2 - \frac{1}{2} mv_o^2$$

" The net WORK done on an object is equal to the change in kinetic energy of the object."

Example W=Fxcosθ

A 70 kg base-runner begins to slide into second base when moving at a speed of 4.0 m/s. The coefficient of kinetic friction between his clothes and the earth is 0.70. He slides so that his speed is zero just as he reaches the base (a) How much energy is lost due to friction acting on the runner? (b) How far does he slide?

$$a)\, W_f = \Delta K$$

$$W_f = 0 - \tfrac{1}{2} m v_o^2 \rightarrow -\tfrac{1}{2}(70)(4)^2$$

$W_f =$ **-560 J**

$$F_f = \mu F_n \rightarrow \mu m g$$

$$= (0.70)(70)(9.8)$$

= 480.2 N

$$W_f = F_f x \cos\theta$$

$$-560 = (480.2)x(\cos 180)$$

$x =$ **1.17 m**

Example

A 5.00 g bullet moving at 600 m/s penetrates a tree trank to a depth of 4.00 cm. (a) Use the work-energy theorem, to determine the average frictional force that stops the bullet.(b) Assuming that the frictional force is constant, determine how much time elapses between the moment the bullet enters the tree and the moment it stops moving

$$W = \Delta K$$

$$W = 0 - \tfrac{1}{2}(0.005)(600)^2$$

$$W_{friction} = \textbf{-900 J}$$

$$W_f = F_f x \cos\theta$$

$$900 = F_f\left(0.04\right)$$

$$F_f = \textbf{22,500 N}$$

$$F_f = F_{NET} = ma \qquad 22,500 = (0.005)a$$

$$a = 4.5\text{x}10^6 \text{ m/s/s}$$

$$v = v_o + at \qquad 0 = 600 + (-4.5x10^6)t$$

$$t = \textbf{1.33x10}^{-4}\textbf{ s}$$

Lifting mass at a constant speed

Suppose you lift a mass upward at a constant speed, $\Delta v = 0$ & $\Delta K=0$. What does the work equal now?

Since you are lifting at a constant speed, your APPLIED FORCE equals the WEIGHT of the object you are lifting.

Since you are lifting you are raising the object a certain "y" displacement or height above the ground.

$$W = Fx, F = mg, x = y(h)$$

$$W = mgh = U$$

$$U = \text{Potential Energy}$$

$$W=\Delta U=mgh-mgh_o$$

When you lift an object above the ground it is said to have POTENTIAL ENERGY

Suppose you throw a ball upward

$$W = \Delta K = \Delta U$$

What does work while it is flying through the air?

GRAVITY

Is the CHANGE in kinetic energy POSITIVE or NEGATIVE?

NEGATIVE

Is the CHANGE in potential energy POSITIVE or NEGATIVE?

POSITIVE

$$-\Delta K = \Delta U$$

$$-(K - K_o) = U - U_o$$

$$-K + K_o = U - U_o$$

$$U_o + K_o = U + K$$

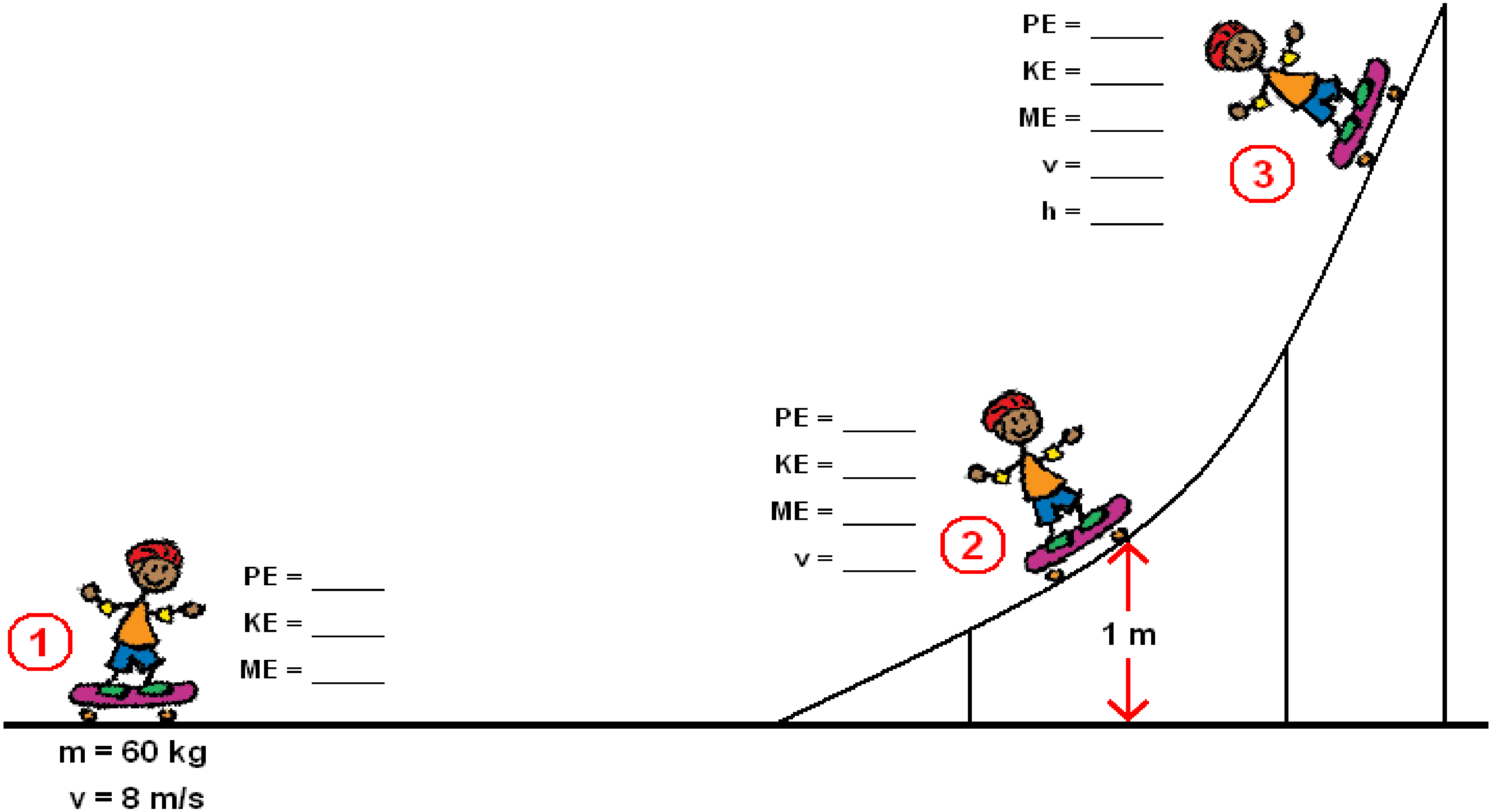
$$Energy_{BEFORE} = Energy_{AFTER}$$

ENERGY IS CONSERVED

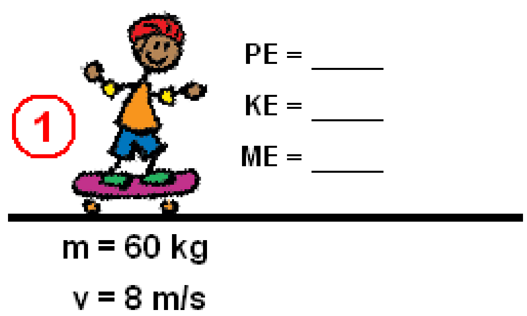
The law of conservation of mechanical energy states: ***Energy cannot be created or destroyed, only transformed!***

Energy Before	Energy After
Am I moving? If yes, K_o	Am I moving? If yes, K
Am I above the ground? If yes, U_o	Am I above the ground? If yes, U

Energy consistently changes forms



Energy consistently changes forms



Am I above the ground? **NO, h = 0, U = 0 J**

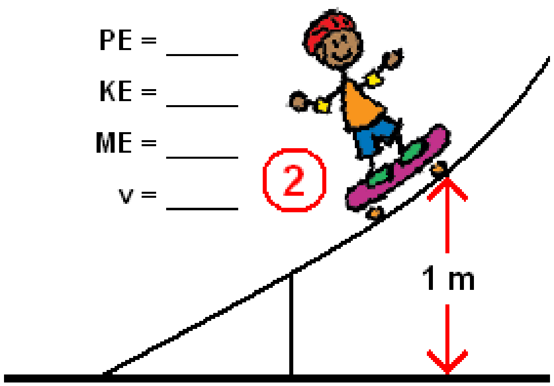
Am I moving? **Yes, v = 8 m/s, m = 60 kg**

$$K = \tfrac{1}{2}mv^2 \rightarrow \tfrac{1}{2}(60)(8)^2$$

$$K = 1920 J$$

Position	m	v	U	K	ME (= U+K)
1	**60 kg**	**8 m/s**	**0 J**	**1920 J**	**1920 J**

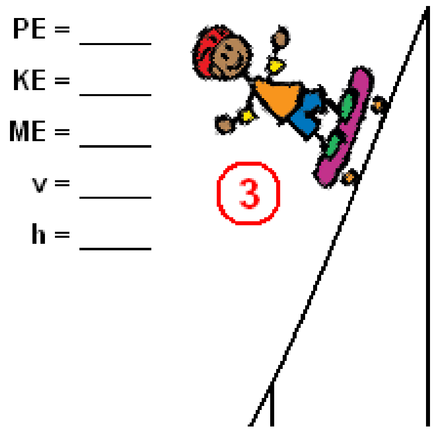
Energy consistently changes forms



Energy Before	= Energy After
K_O	$= U + K$
$1920 =$	$(60)(9.8)(1) + (.5)(60)v^2$
$1920 =$	$588 + 30v^2$
1332	$= 30v^2$
44.4	$= v^2$
v	$= 6.66$ m/s

Position	m	v	U	K	ME
1	60 kg	8 m/s	0 J	1920 J	1920 J
2	60 kg	**6.66 m/s**	**588 J**	**1332 J**	**1920 J**

Energy consistently changes forms



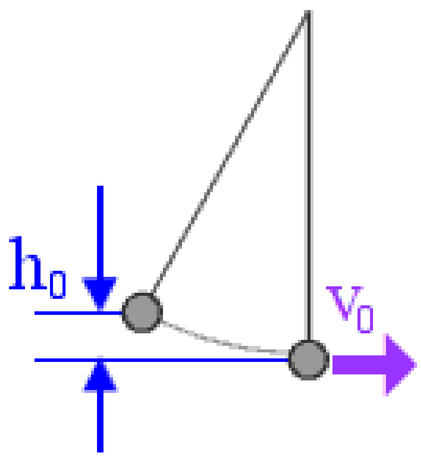
Am I moving at the top? **No, v = 0 m/s**

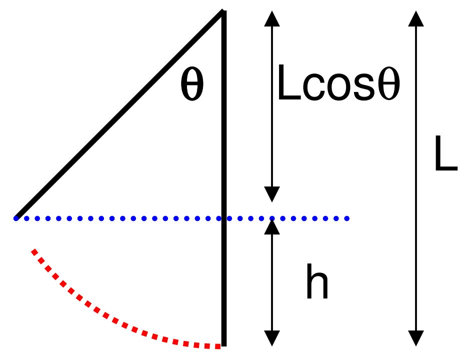
E_B	$= E_A$
Using	position 1
K_o	$= U$
1920	$= mgh$
1920	$=(60)(9.8)h$
h	$= 3.27$ m

Position	m	v	U	K	ME
1	60 kg	8 m/s	0 J	1920 J	1920 J
2	60 kg	6.66 m/s	588 J	1332 J	1920 J
3	60 kg	**0 m/s**	**1920 J**	**0 J**	1920 J

Example

A 2.0 m pendulum is released from rest when the support string is at an angle of 25 degrees with the vertical. What is the speed of the bob at the bottom of the string?





$h = L - L\cos\theta$

$h = 2 - 2\cos\theta$

$h = 0.187$ m

E_B	=	E_A
U_O	=	K
mgh_o	=	$1/2mv^2$
gh_o	=	$1/2v^2$
1.83	=	v^2
1.35 m/s	=	v

Power

One useful application of Energy is to determine the **RATE** at which we store or use it. We call this application **POWER**!

As we use this new application, we have to keep in mind all the different kinds of substitutions we can make.

Unit = WATT or Horsepower

$$P = \frac{W}{t} \rightarrow \frac{Fx}{t} \rightarrow Fv$$

$$P = \frac{mgh}{t}$$

$$P = \frac{\frac{1}{2}mv^2}{t}$$