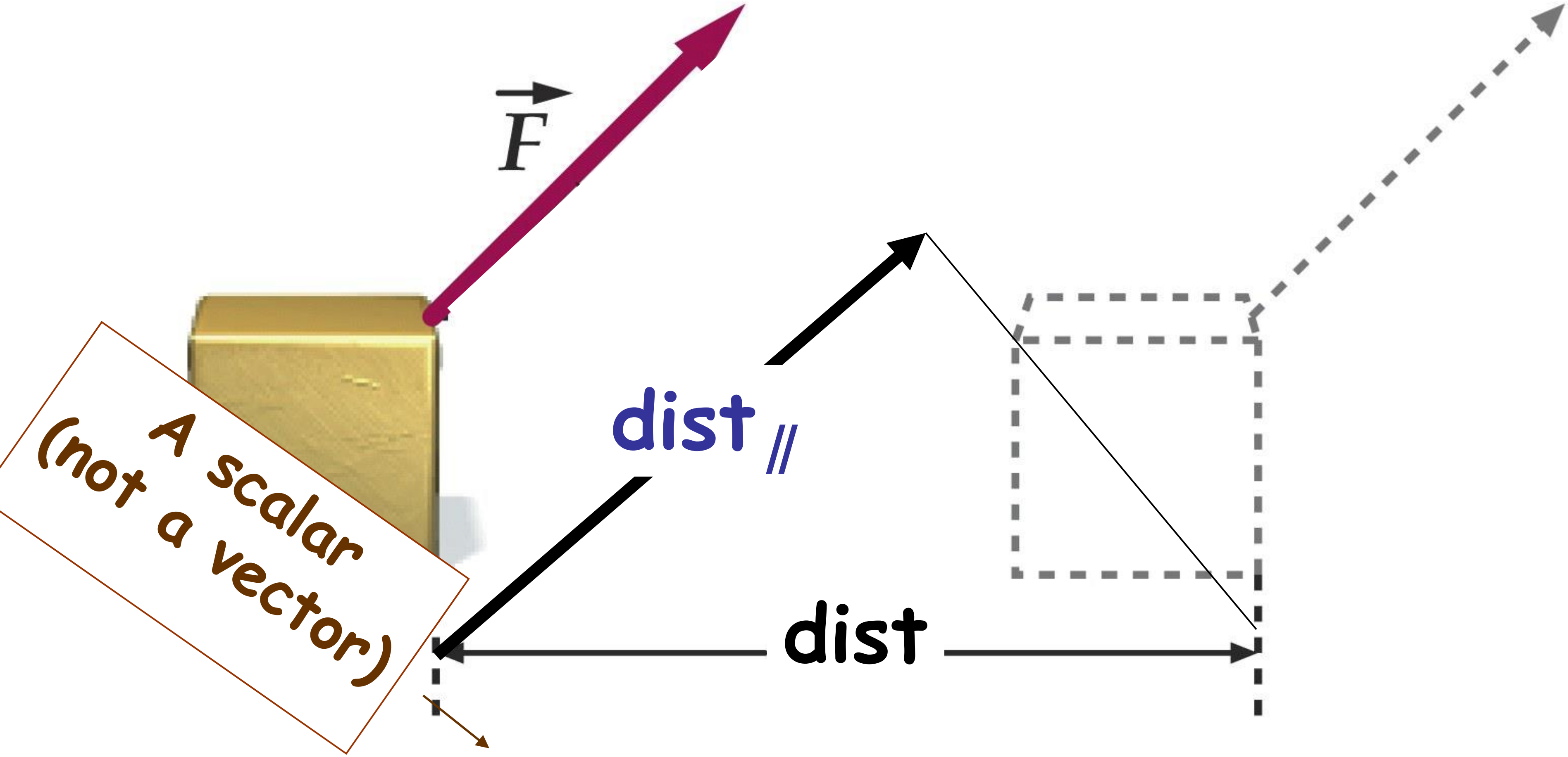
Work and Energy

Physicist's definition of "work"



Work = F × dist$_{//}$

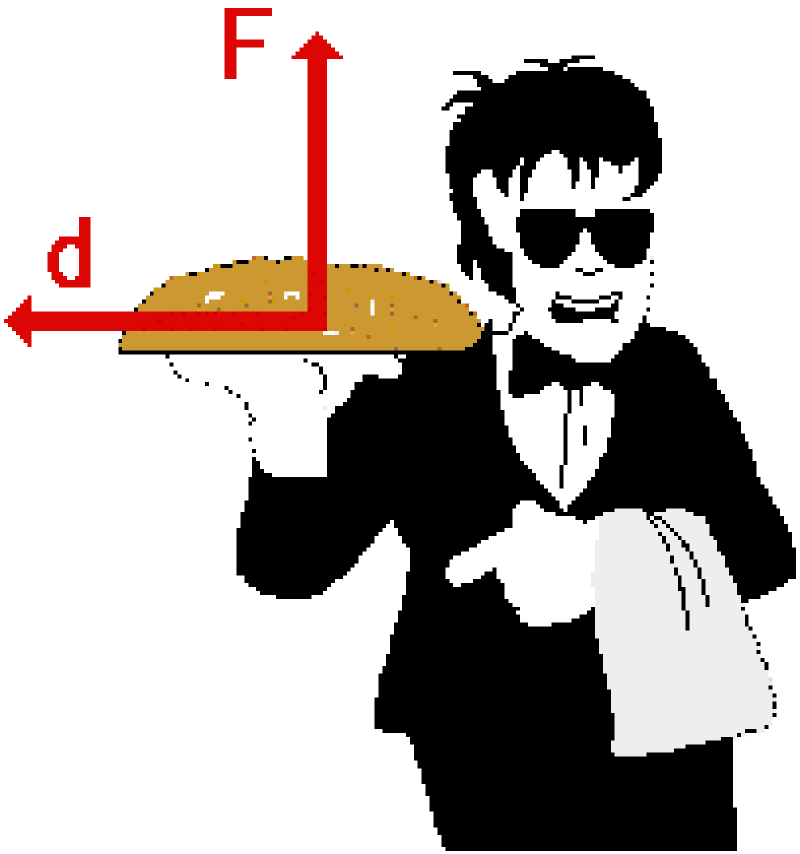
Atlas holds up the Earth

But he doesn't move,
$dist_{//} = 0$

$Work = F \times dist_{//} = 0$

He doesn't do any work!

Garcon does work when he picks up the tray



but not while he carries it around the room

dist is not zero, but $dist_{//}$ is 0

Why this definition?

A vector equation

Newton's 2^{nd} law: $\vec{F} = m\vec{a}$

Definition of work
+ a little calculus

A scalar equation

Work= change in $\frac{1}{2}mv^2$

This scalar quantity is given a special name: kinetic energy

Work = change in KE

This is called:

the Work-Energy Theorem

Units again…

Kinetic Energy = $\frac{1}{2}mv^2$

$$kg\,\frac{m^2}{s^2}$$

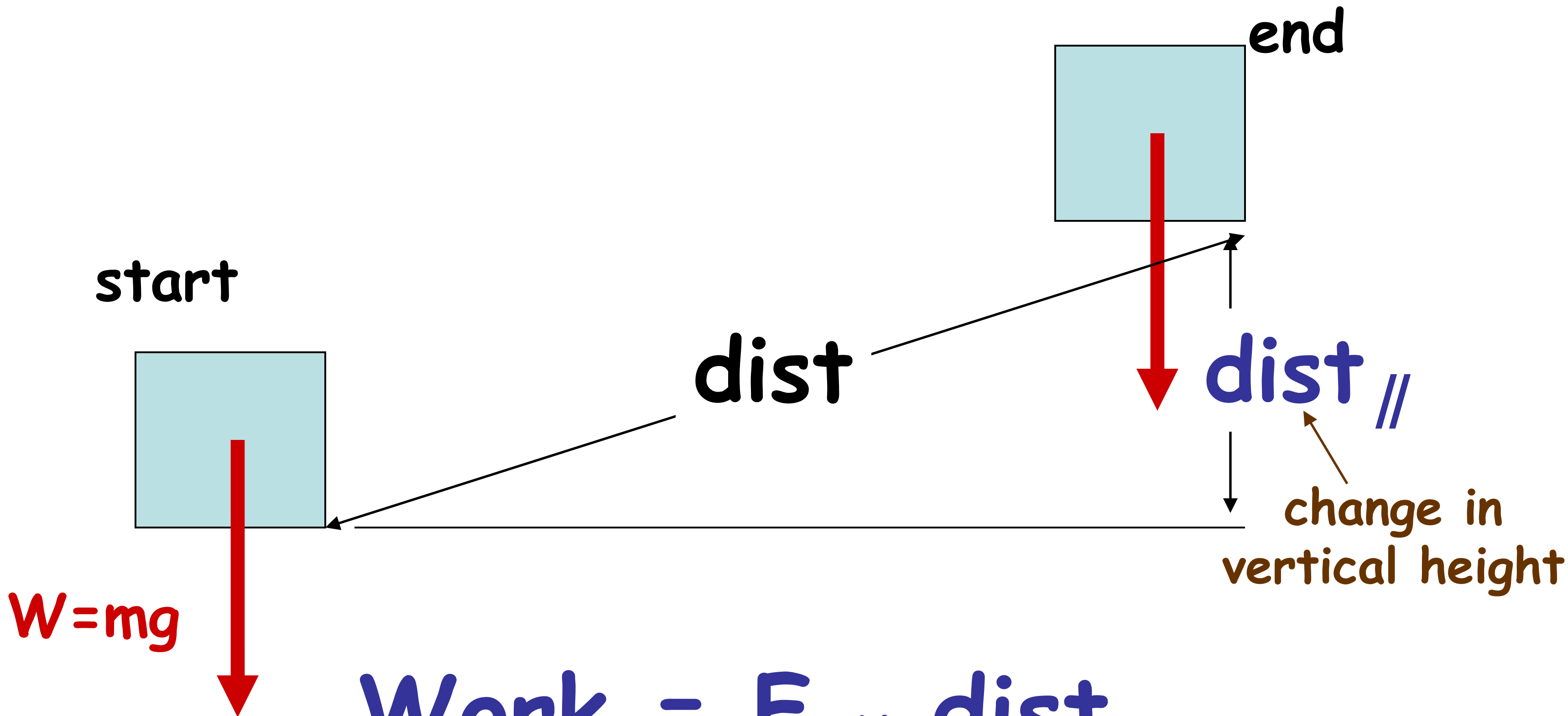
work = F x dist$_{//}$

same!

$$N\;m \;= kg\,\frac{m}{s^2}\,m$$

=1Joule

Work done by gravity



$$Work = F \times dist_{//}$$

$$= -mg \times \text{change in height}$$

$$= -\text{change in } mgh$$

Gravitational Potential Energy

$Work_{grav}$ = -change in mgh

This is called:
"Gravitational Potential Energy" (or PE_{grav})

change in PE_{grav} = $-Work_{grav}$

PE_{grav}

If gravity is the only force doing work….

Work-energy theorem:

-change in mgh = change in $\frac{1}{2} mv^2$

0 = change in mgh + change in $\frac{1}{2} mv^2$

change in ($mgh + \frac{1}{2} mv^2$) = 0

$$mgh + \frac{1}{2} mv^2 = \text{constant}$$

Conservation of energy

$$mgh + \frac{1}{2} mv^2 = \text{constant}$$

Gravitational Potential energy

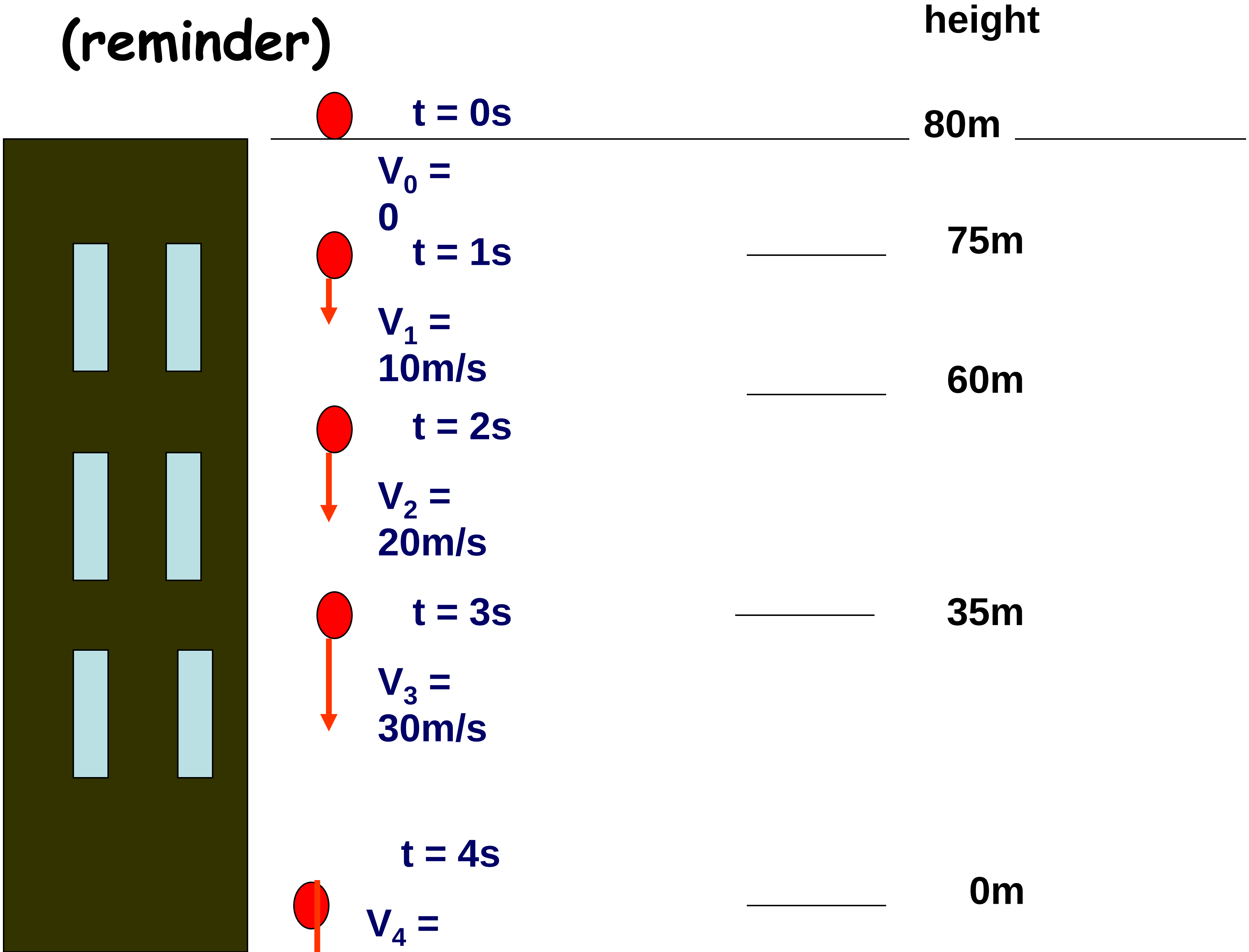
Kinetic energy

If gravity is the only force that does work:

$$PE + KE = \text{constant}$$

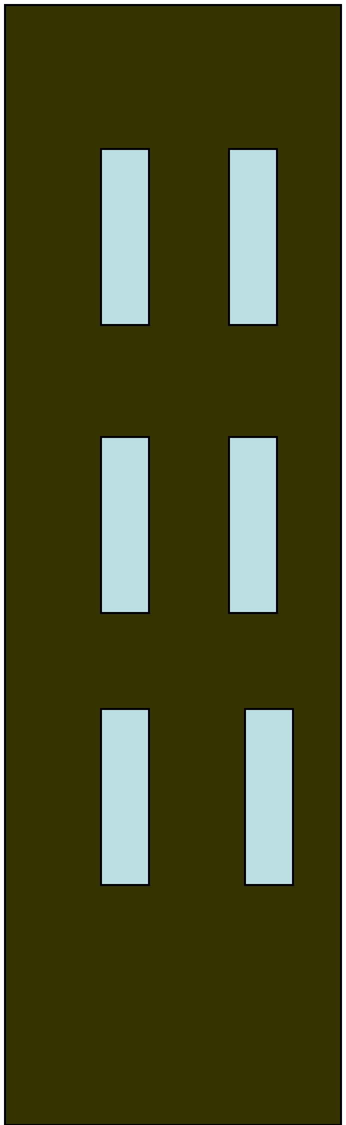
Energy is conserved

Free fall
(reminder)



m=1kg free falls from 80m

mgh ½ mv^2 sum



t = 0s

$V_0 = 0$ $h_0 = 80m$ 800J 0 800J

t = 1s

$V_1 = 10m/s$; $h_1 = 75m$ 750J 50J 800J

t = 2s

$V_2 = 20m/s$; $h_2 = 60m$ 600J 200J 800J

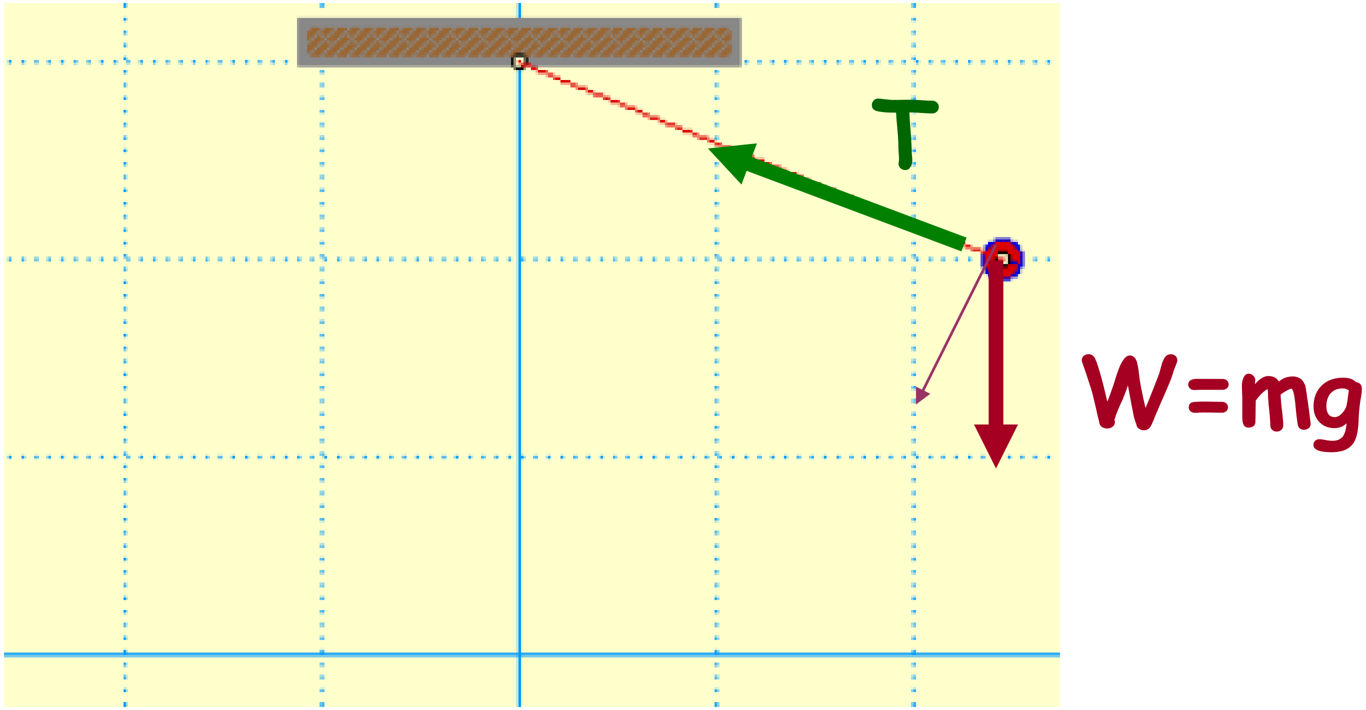
t = 3s

$V_3 = 30m/s$; $h_3 = 35m$ 350J 450J
800J

t = 4s

$V_4 = 40m/s$; $h_4 = 0$ 0 800J

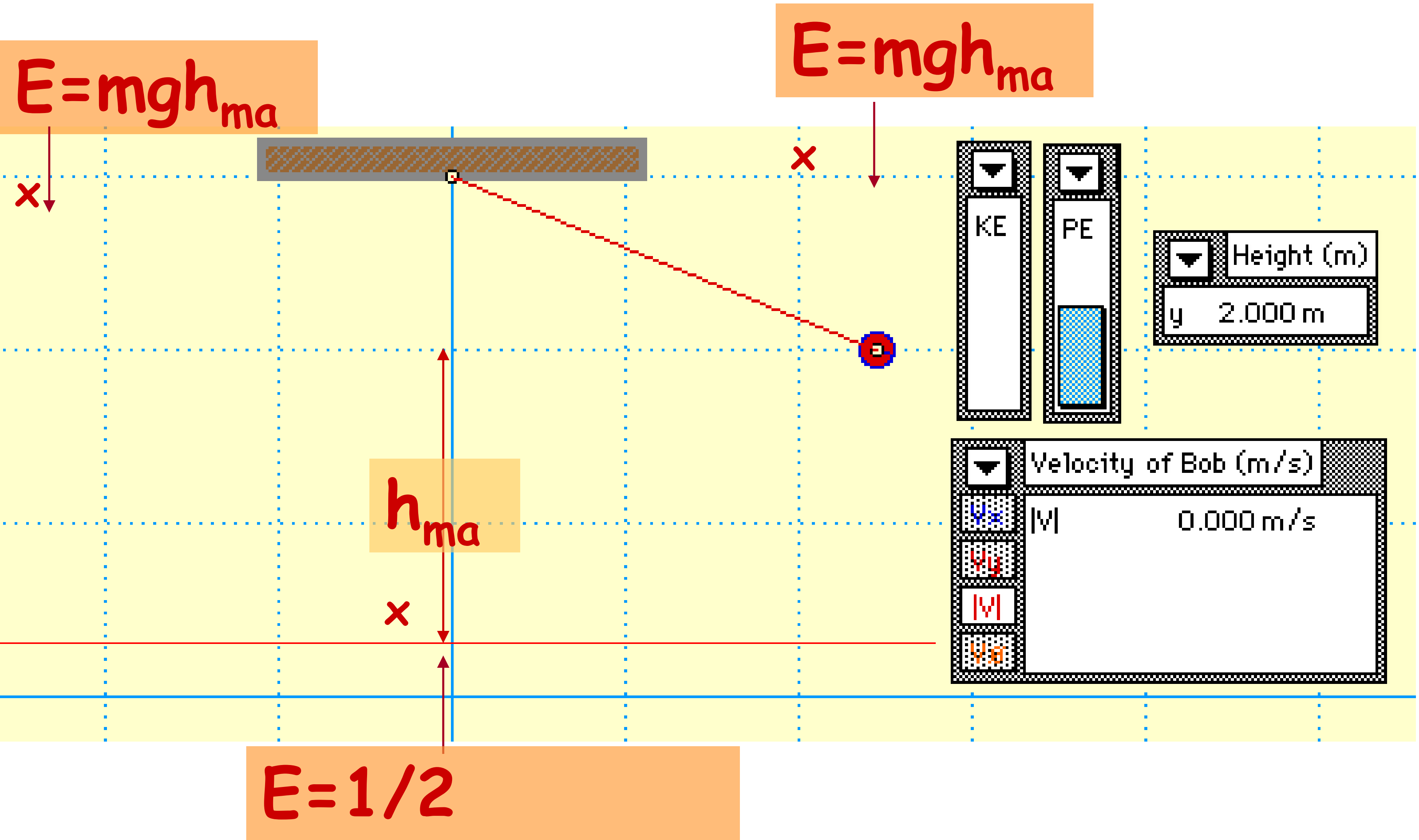
pendulum



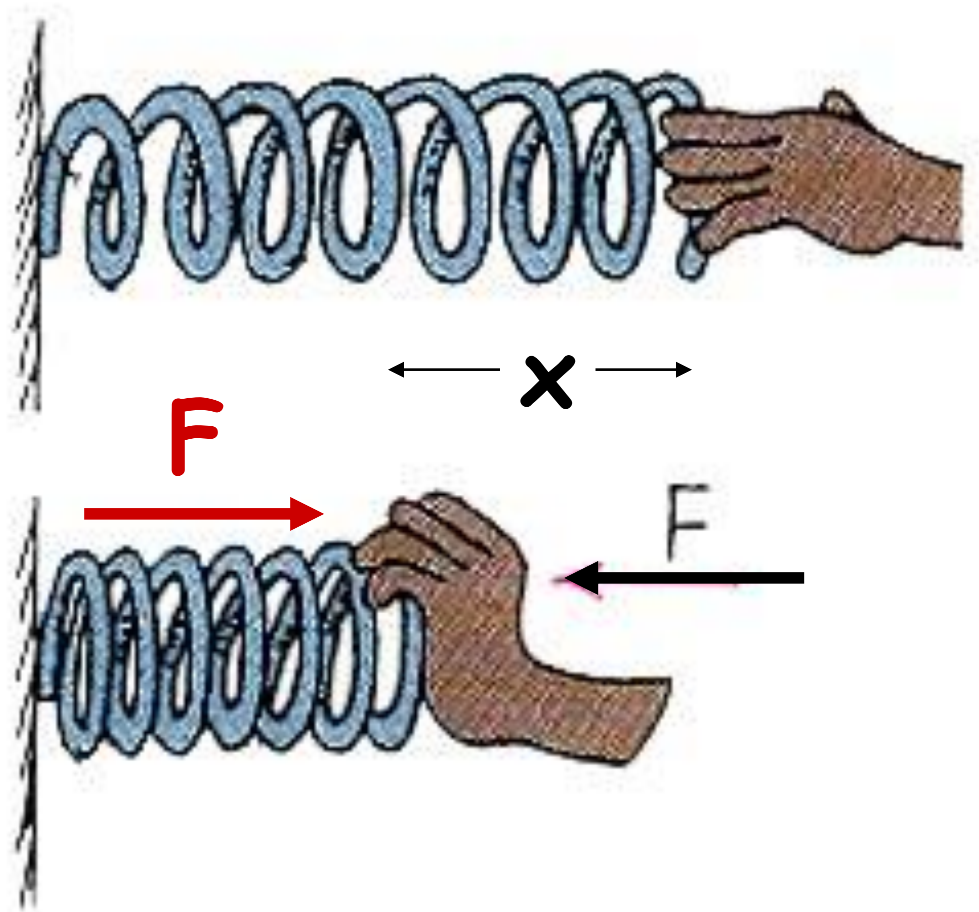
Two forces: T and W

T is always ⊥ to the motion
(& does no work)

Pendulum conserves energy



Work done by a spring



Relaxed Position F=0

I compress the spring

(I do + work; spring does -work)

Work done by spring = - change in $\frac{1}{2}kx^2$

Spring Potential Energy

$Work_{spring}$ = -change in $\frac{1}{2} kx^2$

This is the: "Spring's Potential Energy" (or PE_{spring})

$Work_{spring}$ = -change in PE

change in PE_{spring} = - $Work_{spring}$

If spring is the only force doing work….

Work-energy theorem:

-change in $\frac{1}{2}kx^2$ = change in $\frac{1}{2}mv^2$

0 = change in $\frac{1}{2}kx^2$ + change in $\frac{1}{2}mv^2$

change in ($\frac{1}{2}kx^2 + \frac{1}{2}mv^2$) = 0

$$\frac{1}{2}kx^2 + \frac{1}{2}mv^2 = \text{constant}$$

Conservation of energy springs & gravity

$$mgh + \frac{1}{2}kx^2 + \frac{1}{2}mv^2 = \text{constant}$$

Gravitational potential energy

spring potential energy

Kinetic energy

If elastic force & gravity are the only force doing work:

$$PE_{grav} + PE_{spring} + KE = \text{constant}$$

Energy is conserved

example

grav PE ________

KineticE ________

Spring PE ________

Two types of forces:

"Conservative" forces

forces that do + & – work

- Gravity
- Elastic (springs, etc)
- Electrical forces
- …

-work □ change in PE

"Dissipative" forces

forces that only do – work

- Friction
- Viscosity
- ….

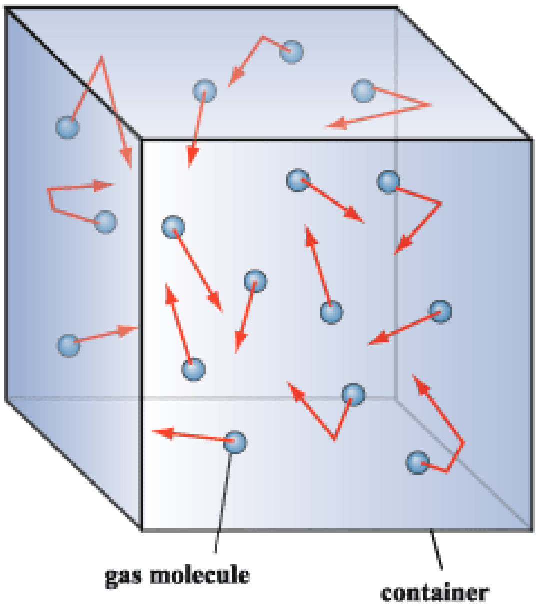
-work □ heat

(no potential energy.)

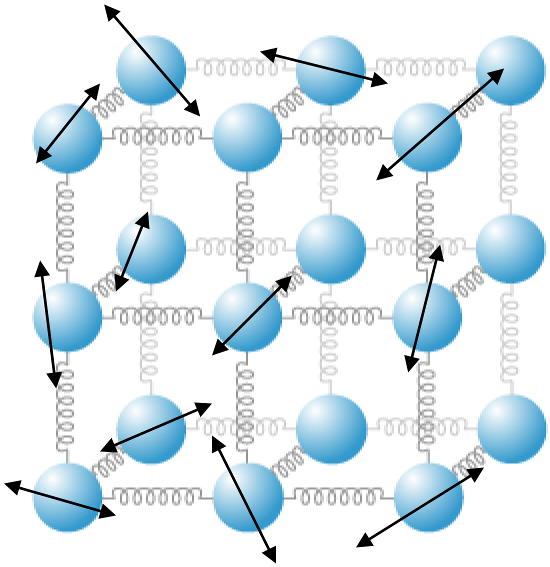

(-)Work done by friction□ heat

Thermal atomic motion

Air



solid



Heat energy= KE and PE associated with the random thermal motion of atoms

Work-energy theorem (all forces)

$Work_{fric}$ = change in (PE+KE)

Work done dissipative Forces (always -)

potential energy From all Conservative forces

Kinetic energy

$Work_{fric}$ = -change in heat energy

energy

-change in Heat Energy = change in (PE+KE)

Work – Energy Theorem (all forces)

0 = change in Heat Energy +
change in (PE+KE)

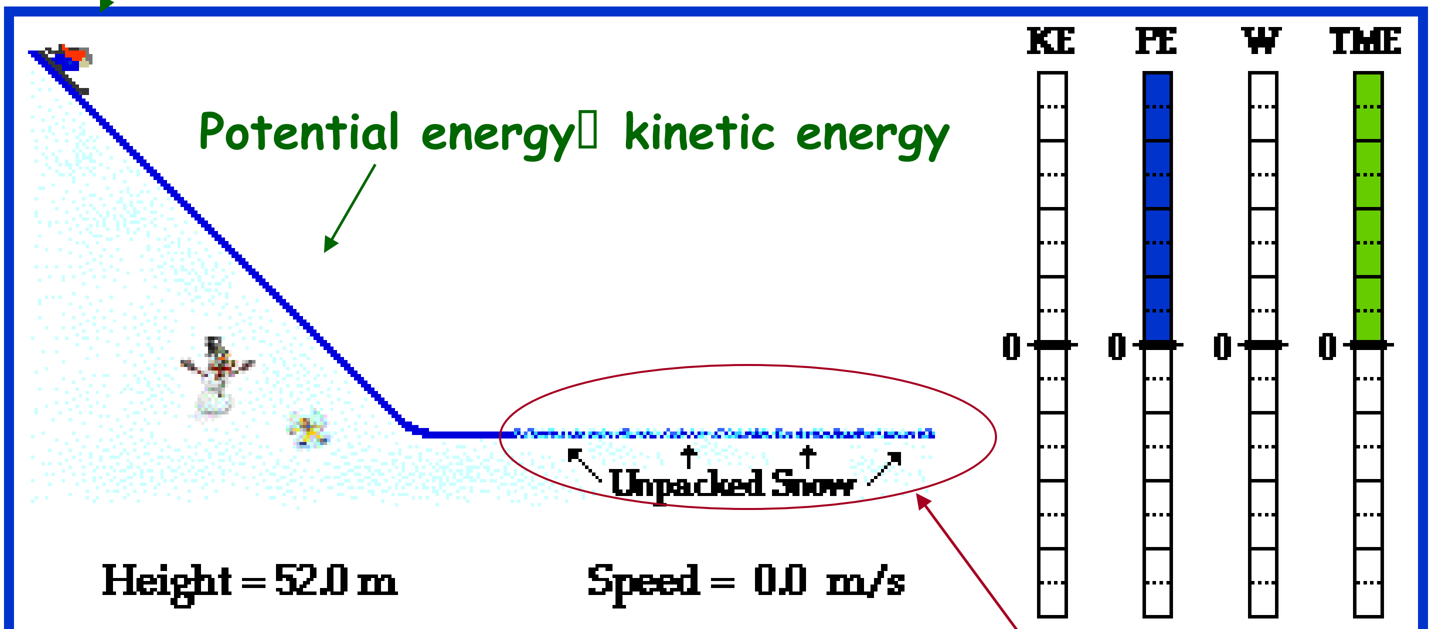
0 = change in (Heat Energy+PE+KE)

Heat Energy + PE + KE = constant

Law of Conservation of Energy

Energy conversion while skiing

Potential energy



Potential energy kinetic energy

Friction: energy gets converted to heat

Units again

Heat units:

1 calorie = heat energy required to raise the temp of 1 gram of H_2O by 1° C

$Kg\ m^2/s^2$

1 calorie= 4.18 Joules

Food Calories

1 Calorie = 1000 calories = 1Kcalorie

The Calories you read on food labels

1 Calorie= 4.18×10^3 Joules

8×10^5 J

2×10^6 J

Power

Rate of using energy:

$$\text{Power} = \frac{\text{amout of energy}}{\text{elapsed time}}$$

Units: $$1\ \frac{\text{Joule}}{\text{second}} = 1\ \text{Watt}$$

A 100 W light bulb consumes 100 J of electrical energy each second to produce light

Other units

Over a full day, a work-horse can have an average work output of more than 750 Joules each second

1 Horsepower = 750 Watts

Kilowatt hours

$$\text{Power} = \frac{\text{energy}}{\text{time}} \quad \Rightarrow \quad \text{energy} = \text{power} \times \text{time}$$

$\Rightarrow$ power unit × time unit = energy unit

Elec companies use: Kilowatts (10^3 W) × hours (3600 s)

1 kilowatt-hour = 1kW-hr

$= 10^3 W \times 3.6 \times 10^3 s = 3.6 \times 10^6 J$

HECO charges us about 15 cents/kW-hr

Thank you