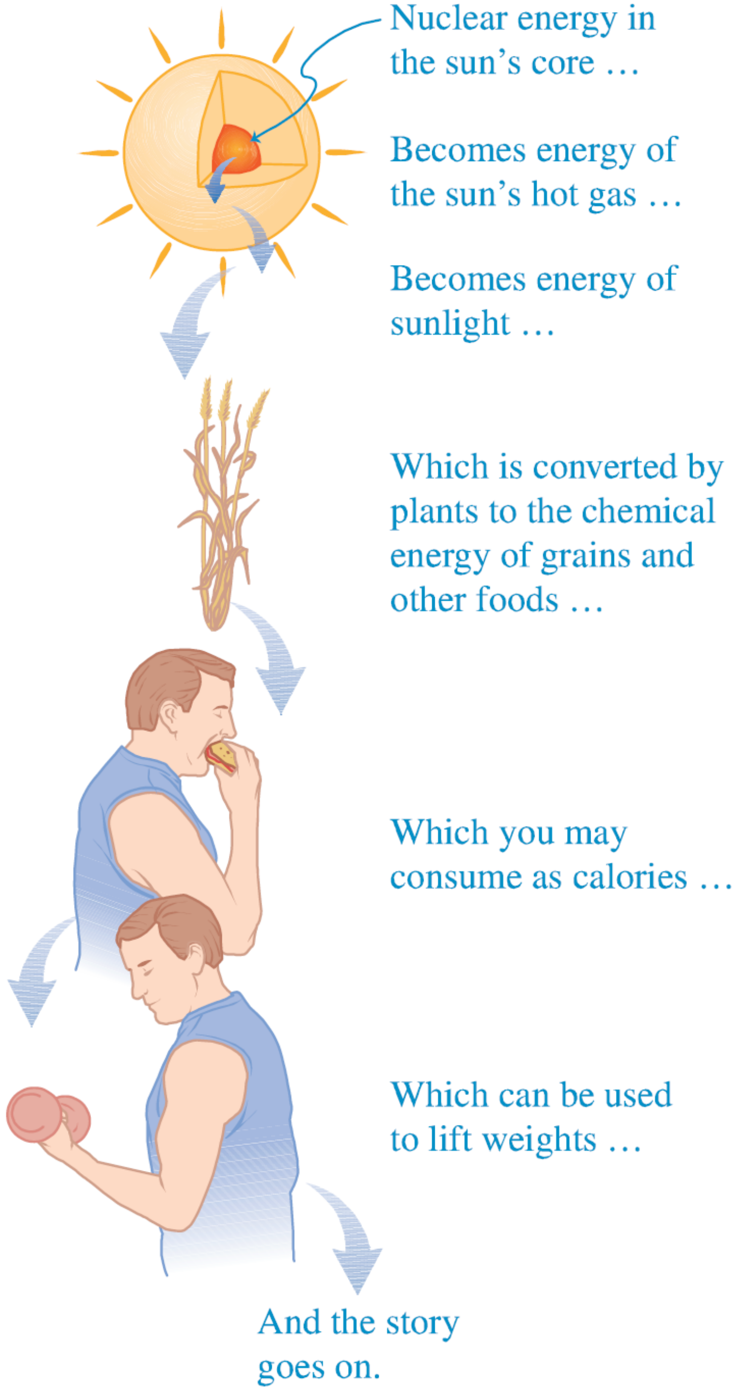
Work and Energy and power   Chapter 7

Goals for Chapter 7

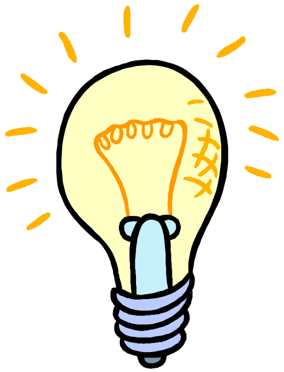
- Overview energy.
- Study work as defined in physics.
- Relate work to kinetic energy.
- Consider work done by a variable force.
- Study potential energy.
- Understand energy conservation.
- Include time and the relationship of work to power.

Energy: Forms & Transforr

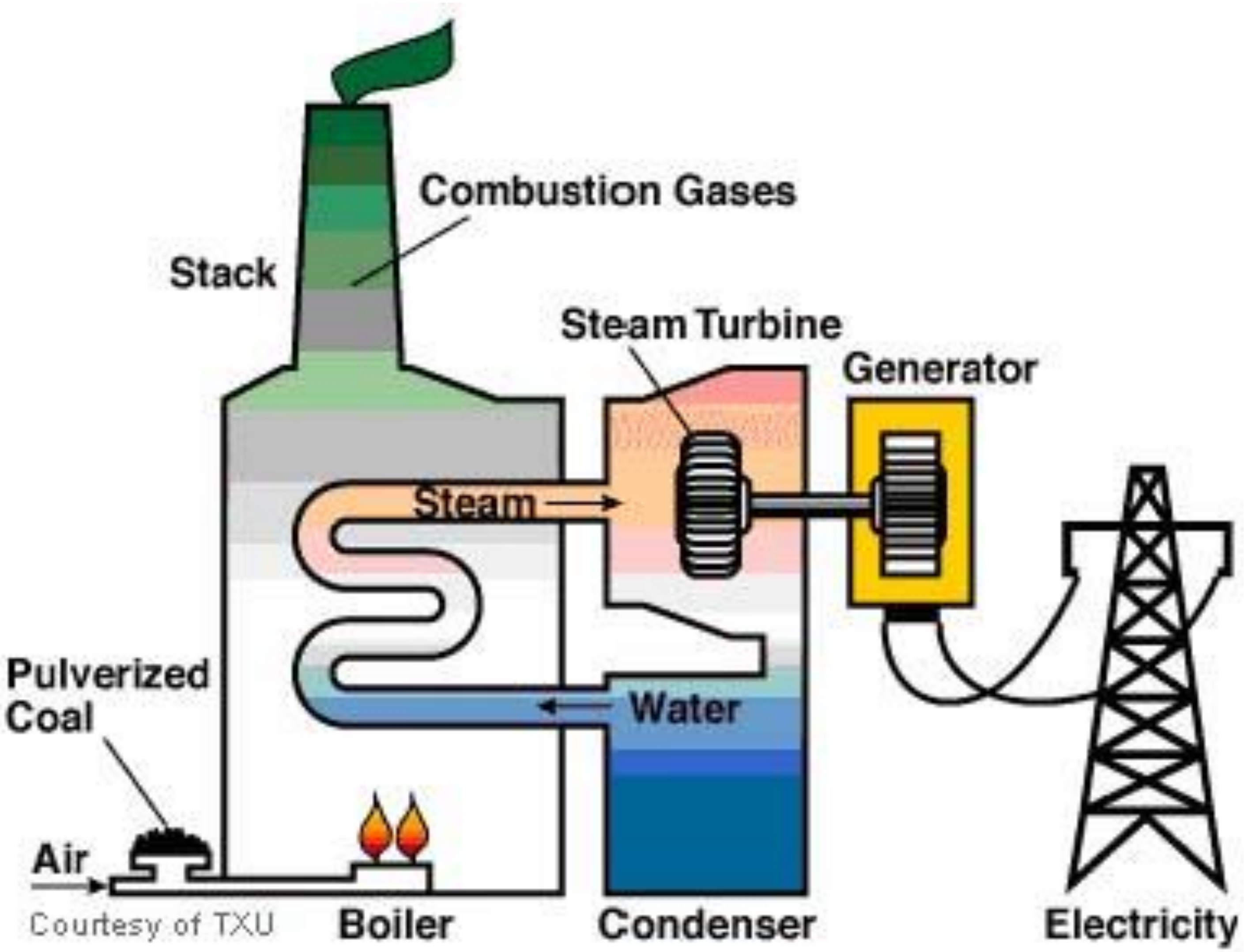
- Energy comes in many forms
  - Mechanical
  - Thermal
  - Electrical
  - Nuclear
  - Chemical
  - Wave



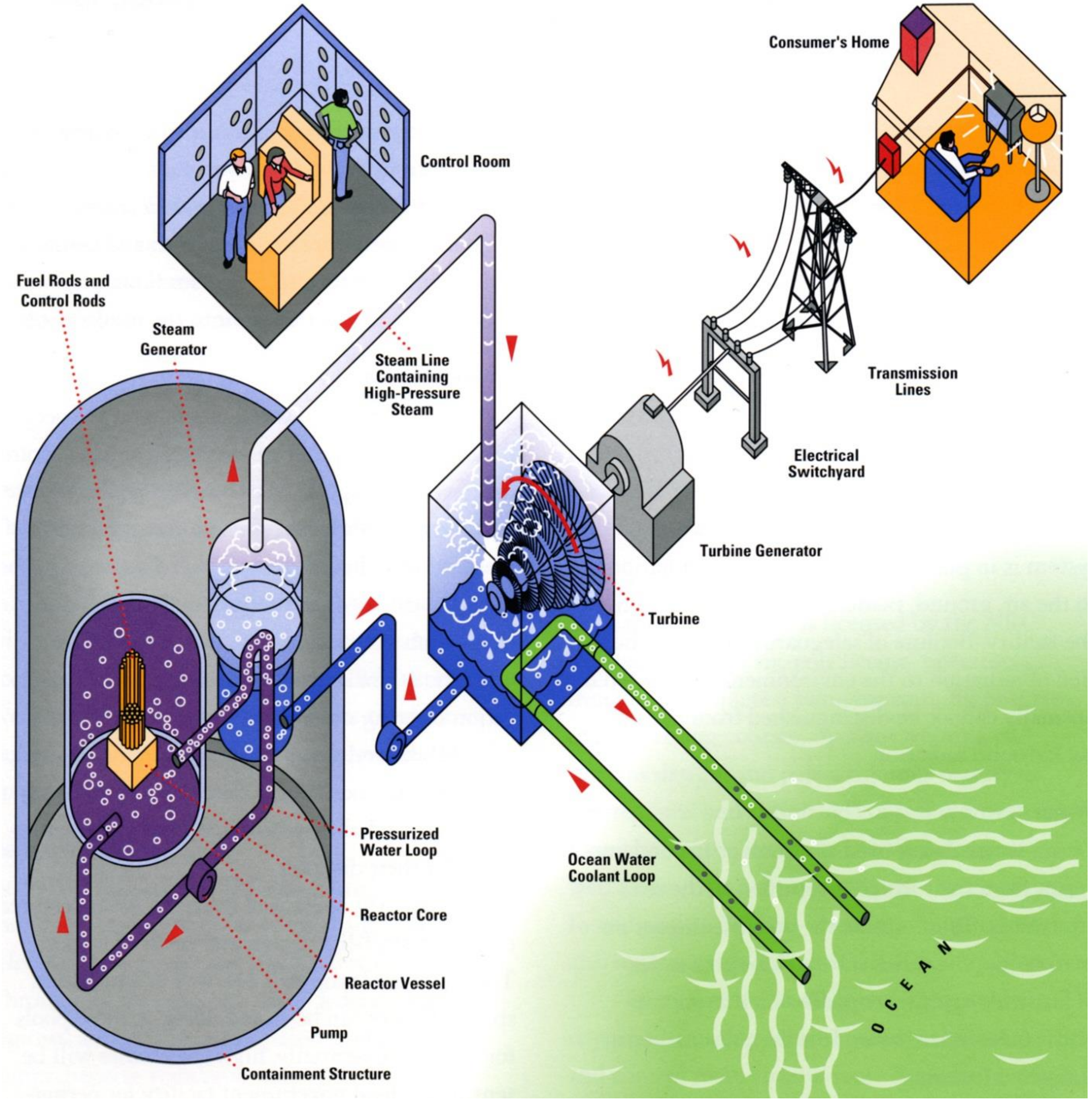
Energy transformations



A Power station

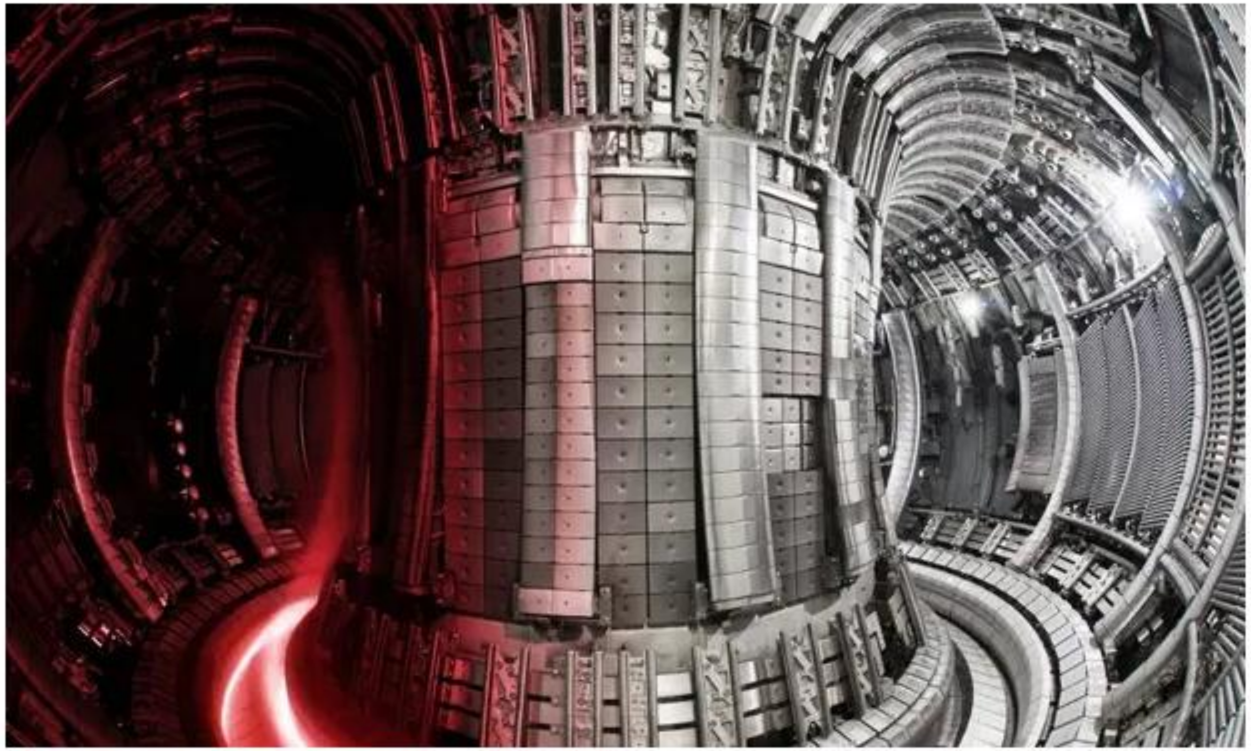


A Nuclear Power Plant



Nuclear fusion heat record a 'huge step' in quest for new energy source

Oxfordshire scientists' feat raises hopes of using reactions that power sun for low-carbon energy



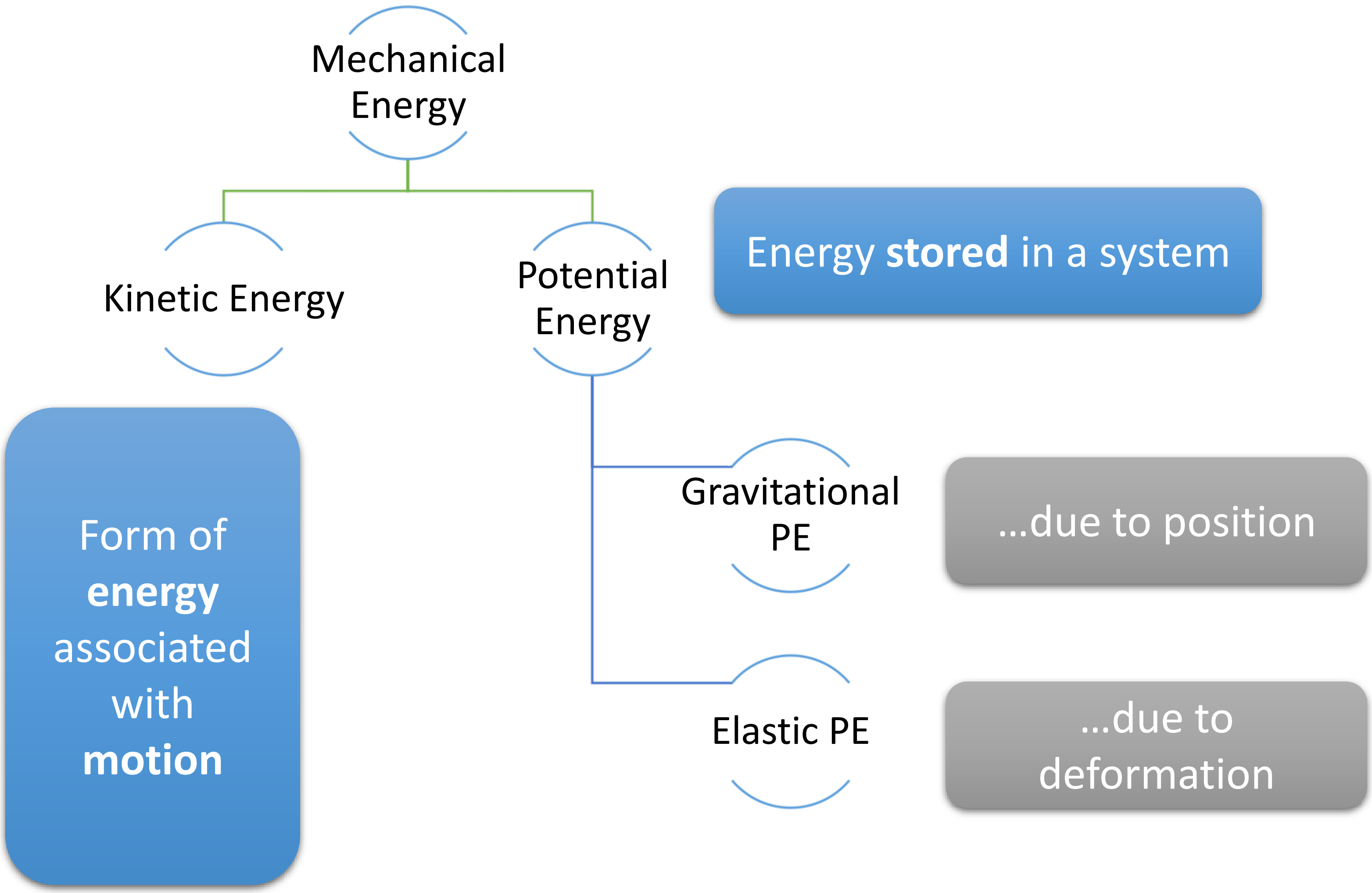
The interior of the JET, where an experiment generated 59 megajoules of heat, beating the 1997 record of 21.7 megajoules. Photograph: UKAEA

The prospect of harnessing the power of the stars has moved a step closer to reality after scientists set a new record for the amount of energy released in a sustained fusion reaction.

Energy Essentials (1)

- Energy can take various forms (our focus is mechanical energy)
- Energy is a *scalar* quantity.
- The SI unit of energy is the Joule (J).

Mechanical Energy



Mechanical Energy:
Kinetic Energy

Kinetic Energy

For a object of mass m and speed v, its kinetic energy is

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

Example 1

A runner has a mass of 80.0 kg and a kinetic energy of 4.0 kJ. What is her velocity?

Ans = 10 m/s

$m = 80.0$ Kg

$KE = 4.0 \times 10^3$ J

v ?

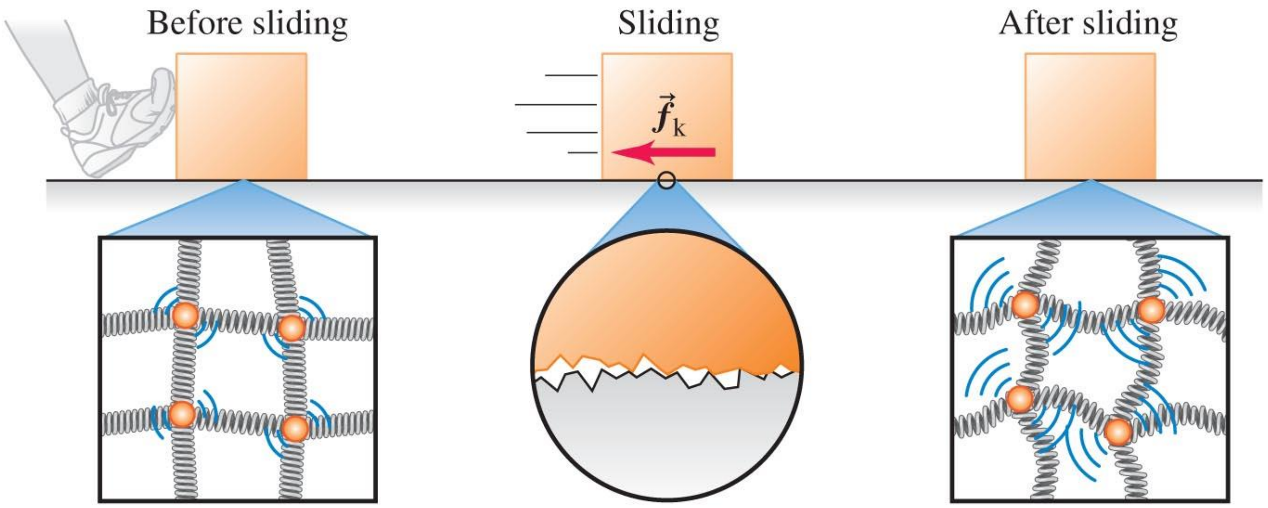
$$\boxed{KE = \frac{1}{2} m v^2}$$

$$4.0 \times 10^3 = \frac{1}{2} 80.0 \; v^2$$

$v = 10.0$ m/s

Internal Energy Can be "Lost" as Heat

- Atoms and molecules of a solid can be thought of as particles vibration randomly on spring like bonds. This vibration is an an example of internal energy.
- Energy can be dissipated by heat (motion transferred at the molecular level). This is referred to as dissipation.



At room temperature, atoms vibrate moderately.

Kinetic friction due to small-scale surface roughness slows block.

Friction has converted the kinetic energy of the sliding block to stronger atomic vibrations (internal energy).

Mechanical Energy:
Gravitational potential energy

Gravitational Potential Energy

For a object of mass m at vertical position y, its gravitational potential energy is

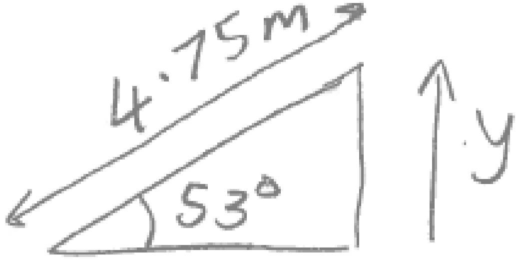
$$U_g = mgy$$

Example 2

A 575 N woman climbs a staircase that rises at 53° above the horizontal and is 4.75 m long. Assuming her speed to be constant, find the change in her gravitational potential energy.

Ans = 2181 J

$575\ N = mg$



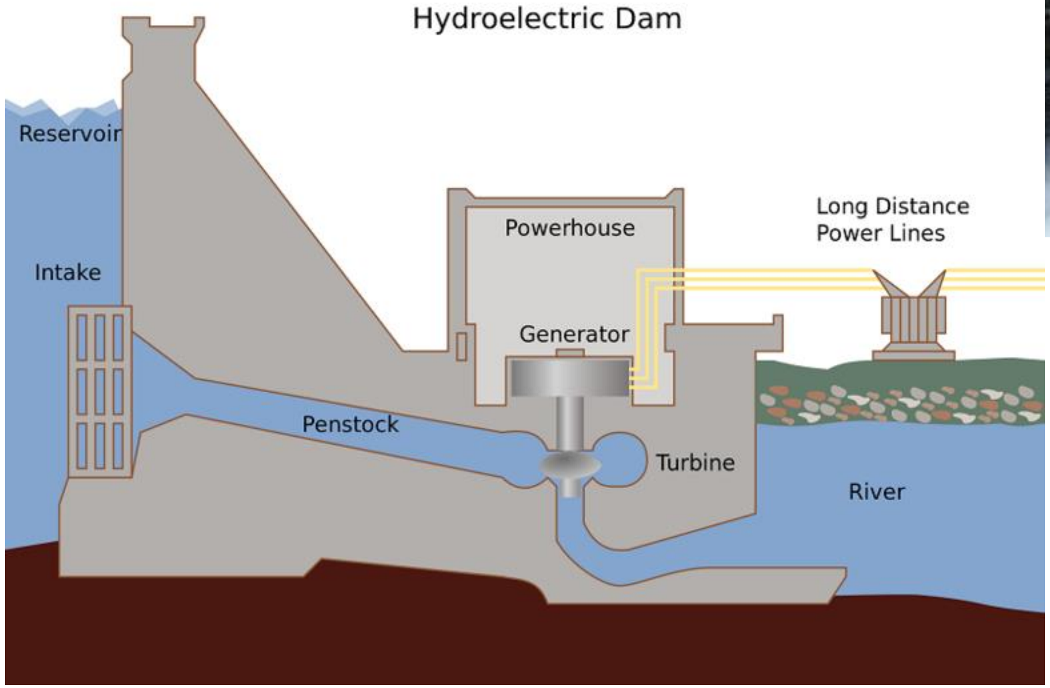
$S\frac{O}{H}$ $C\frac{A}{H}$ $T\frac{O}{A}$

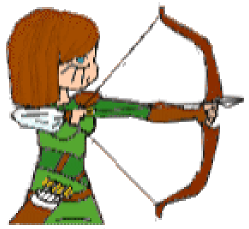
$y = 4{\cdot}75 \sin 53^\circ$

$U_g = (m \quad g) \quad y$

$= 575 \quad 4{\cdot}75 \sin 53^\circ$

$= 2181\ J$


Hydroelectric Dam
Reservoir
Intake
Penstock
Powerhouse
Generator
Turbine
Long Distance
Power Lines
River

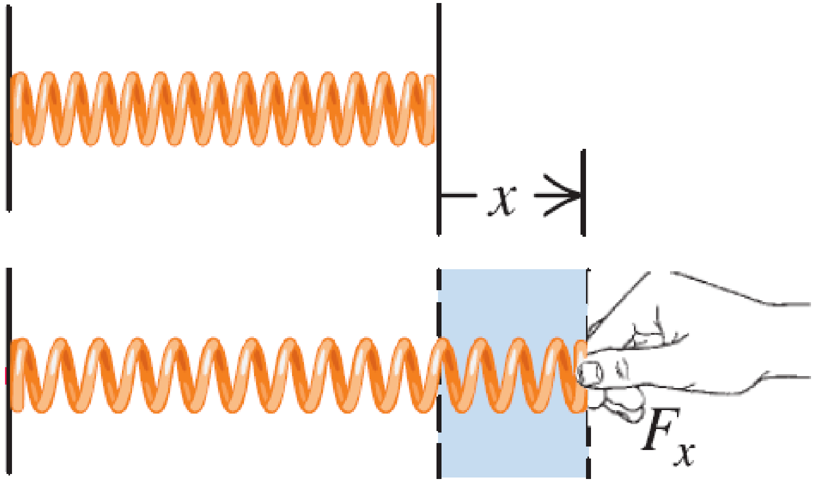
Mechanical Energy:

Elastic Potential Energy

Hooke's Law

For an elastic spring, the applied force F is proportional to the extension/compression x.

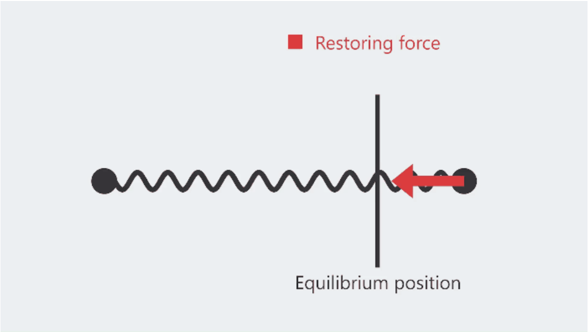
$$F \propto x$$
$$F = kx$$



Elastic Potential Energy

When a force F stretches/compresses a spring by a distance x from its equilibrium position, the elastic potential energy it stores is

$$U_e = \frac{1}{2}kx^2$$



Hooke's Law: $F = kx$

Elastic Potential Energy: $U_e = \frac{1}{2}kx^2$

Example 3

To stretch a certain spring by 2.5 cm from its equilibrium position requires 8.0 J of work.

(a) What is the force constant of this spring?

(b) What was the maximum force required to stretch it by that distance?

a) k = 25600 N/m b) F = 640 N

$x = 2.5\,cm = 2.5 \times 10^{-2}\,m$

$W = U_e = \frac{1}{2} k x^2 = 8.0\,J$

(a) k? $8.0 = \frac{1}{2} k (2.5 \times 10^{-2})^2$

$k = 25600\ N/m$

(b) $F = k x$

$= 25600 (2.5 \times 10^{-2})$

$= 640\,N$

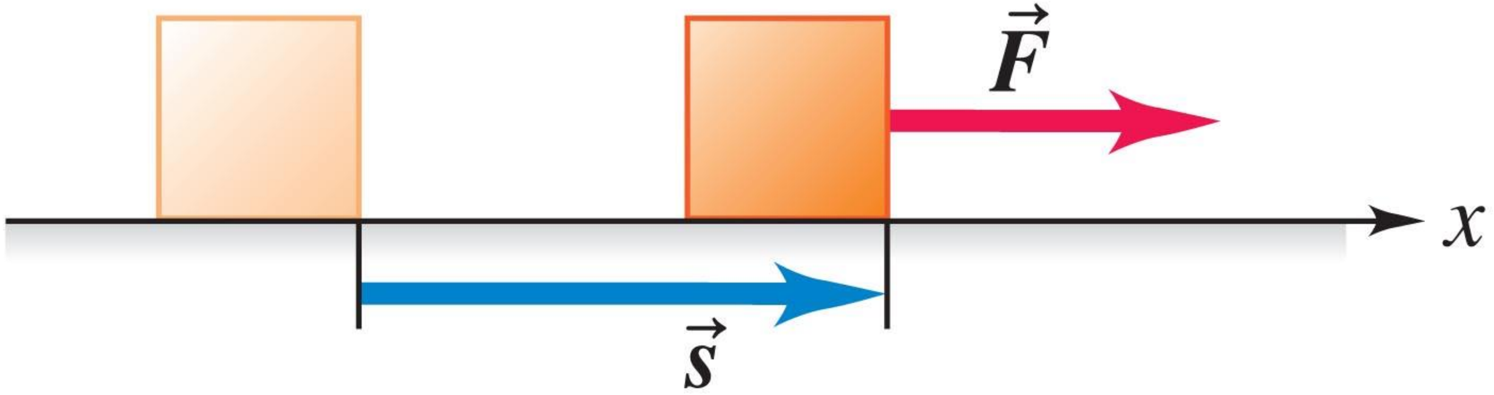
WORK DONE

=

ENERGY TRANSFERRED

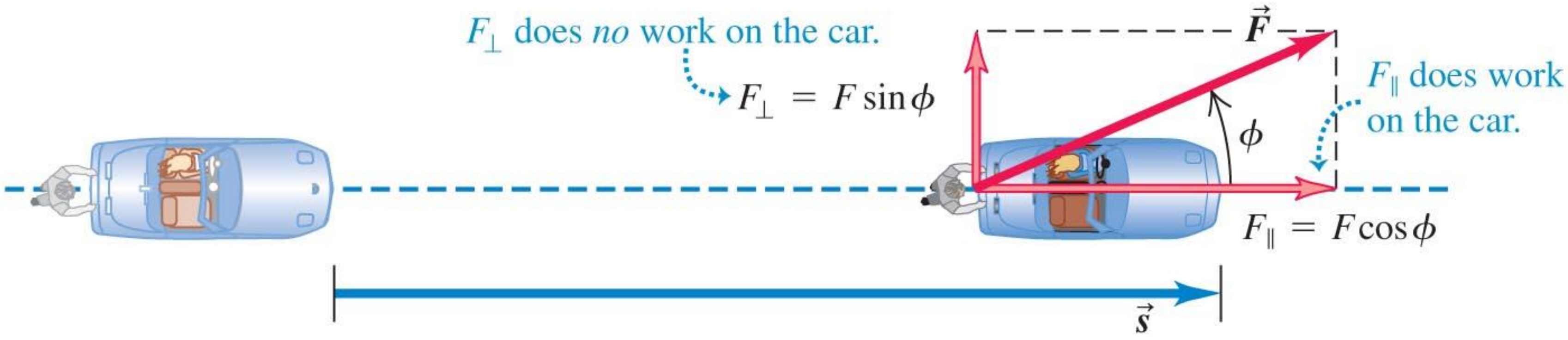
What is "Work" as Defined in Physics?

- Formally, work is the product of a constant force ***F*** through a parallel displacement ***s***.
- Work is the product of the component of the force in the direction of displacement and the magnitude *s* of the displacement.



Consider Only Parallel *F* and *S* – Figure 7.9

- Forces applied at angles must be resolved into components.

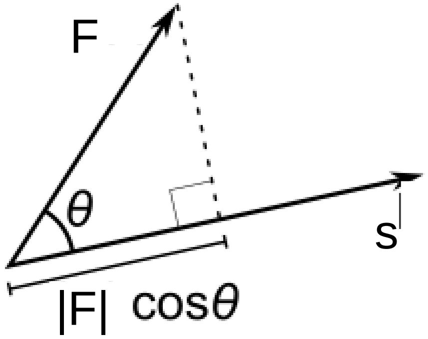


$$W = F_{\parallel} s$$

- *W* is a scalar quantity that can be positive, zero, or negative.
- If $W > 0$ ($W < 0$), energy is added to (taken from) the system.

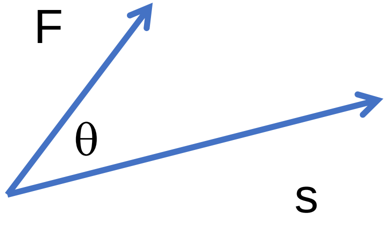
WORK = F0RCE TIMES DISTANCE MOVED IN THE DIRECTION OF THE FORCE

WORK = FORCE COMPONENT IN THE DIRECTION OF MOTION TIMES THE DISTANCE



θ Is the angle between the two vectors

F has a component $|F| \cos \theta$ in the direction of s
So $W = |F| \cos \theta \; |s|$

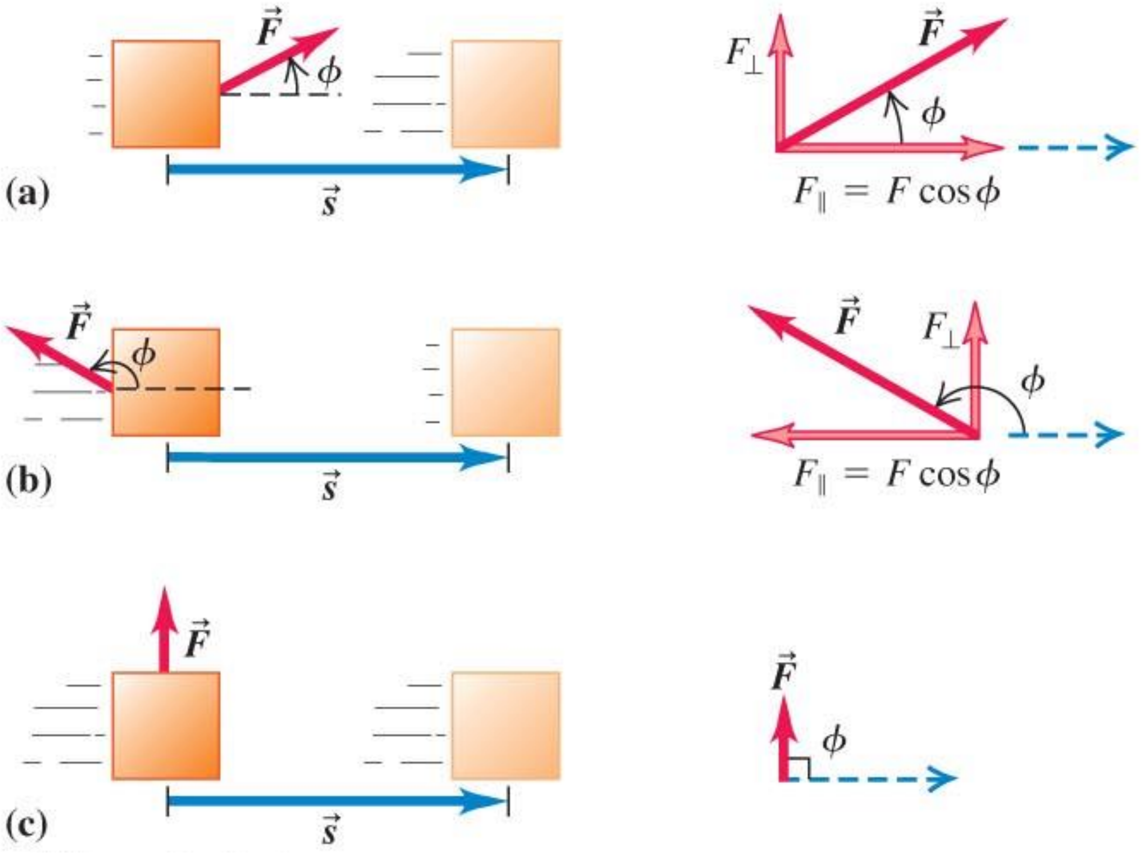


Mathematically this is a dot product.
Such that

$W = \mathbf{F}.\mathbf{s} = |F|\, |s| \cos \theta$

Two ways of looking at the same thing
(note the product of the two vectors is a scalar)

Applications of Force and Resultant Work



The force has a component in the direction of displacement:

- The work on the object is positive. (The object speeds up.)
- $W = F_\parallel s = (F\cos\phi)s$

The force has a component opposite to the direction of displacement:

- The work on the object is negative. (The object slows down.)
- $W = F_\parallel s = (F\cos\phi)s$
- Mathematically, $W < 0$ because $F\cos\phi$ is negative for $90° < \phi < 270°$.

The force is perpendicular to the direction of displacement:

- The force does *no* work on the object.
- More generally, if a force acting on an object has a component $F_\perp$ perpendicular to the object's displacement, that component does no work on the object.

Work

Work done by a CONSTANT force

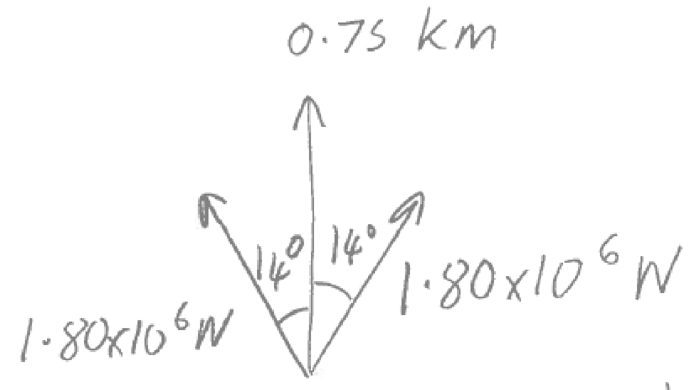
If the angle between $\vec{F}$ and $\vec{s}$

is ϕ, then

$$W = F_{||}s$$
$$W = (F \cos\phi)\, s$$

Example 5

Two tugboats pull a disabled supertanker. Each tug exerts a force of 1.80×10^6 N, one 14° west of north and the other 14° east of north, as they pull the tanker 0.75 km towards the north. What is the total work done on the tanker?



distance

$$WD = F \cos\theta \; s$$

$$= 2\left(1.80\times10^{6}\cos 14\right)\,0.75\times10^{3}$$

2 tugboats

$$= 2.62\times10^{9}\ \text{J}$$

Example

A tennis player hits a 58.0 g tennis ball so that it goes straight up and reaches a maximum height of 6.17 m.

(a) How much work does gravity do on the ball on the way up?

(b) On the way down?

ANS a) -3.51 J

7.2. Set Up: Use $W = F_{\parallel}s = (F\cos\phi)s$. On the way up, the displacement is upward and the gravity force is downward, so $\phi = 180^\circ$. On the way down, both the displacement and force are downward, so $\phi = 0^\circ$.

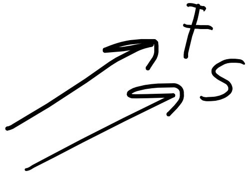
Solve: On the way up: $W = (mg\cos 180^\circ)s = (5.80\times 10^{-2}\text{ kg})(9.80\text{ m/s}^2)(\cos 180^\circ)(6.17\text{ m}) = -3.51\text{ J}$

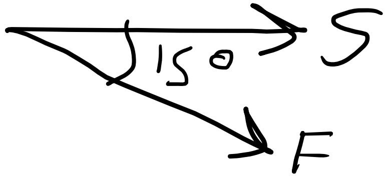
On the way down: $W = (mg\cos 0^\circ)s = (5.80\times 10^{-2}\text{ kg})(9.80\text{ m/s}^2)(\cos 0^\circ)(6.17\text{ m}) = 3.51\text{ J}$

Reflect: When the force and displacement are in opposite directions, the work done is negative.

7.2 Work

1. • A fisherman reels in 12.0 m of line while landing a fish, using a constant forward pull of 25.0 N. How much work does the tension in the line do on the fish?





3. • A boat with a horizontal tow rope pulls a water skier. She skis off to the side, so the rope makes an angle of 15.0° with the forward direction of motion. If the tension in the rope is 180 N, how much work does the rope do on the skier during a forward displacement of 300.0 m?

angle between F + S

$W = F s \cos\theta$

ANS 1) 300J 3) 5.22 x 10^4 J

7.1. Set Up: Assume the fisherman is holding the pole straight out in front of him so that the pole and fishing line are roughly parallel to the water. Thus $\phi = 0°$ may be used in the relation $W = F_{\parallel}s = (F\cos\phi)s$.

Solve: $W = F_{\parallel}s = (F\cos\phi)s = [(25.0\text{ N})(\cos 0°)](12.0\text{ m}) = 300\text{ J}$

Reflect: Because $\phi = 0°$, all of the force that the fisherman applies through the line is used to perform work on the fish.

***7.3. Set Up:** Use $W = F_{\parallel}s = (F\cos\phi)s$ with $\phi = 15.0°$.

Solve: $W = (F\cos\phi)s = (180\text{ N})(\cos 15.0°)(300.0\text{ m}) = 5.22\times 10^{4}\text{ J}$

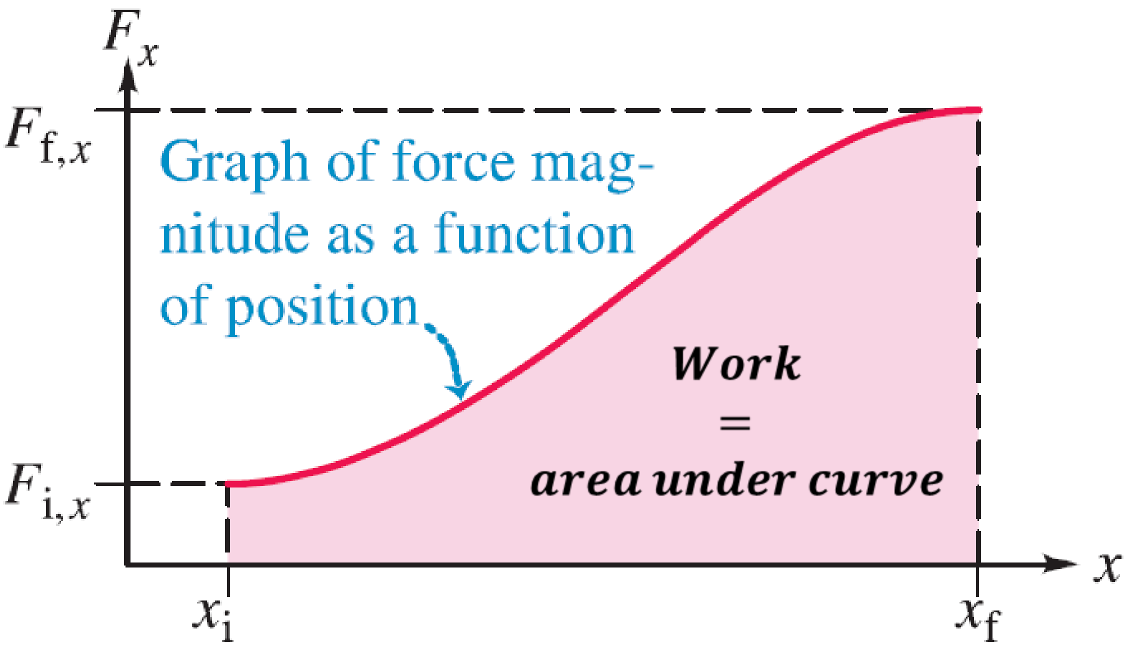
Reflect: Since $\cos 15.0° \approx 0.97$, the relatively small angle of $15.0°$ allows the boat to apply approximately 97% of the 180 N force to pulling the skier.

Work done by a variable force

7.4

Force changes from F_i to F_f over the displacement x_i to x_f.

Work done by this force equals the area under the F-x curve from the initial to the final position



Work done by a variable force

Stretching an elastic spring

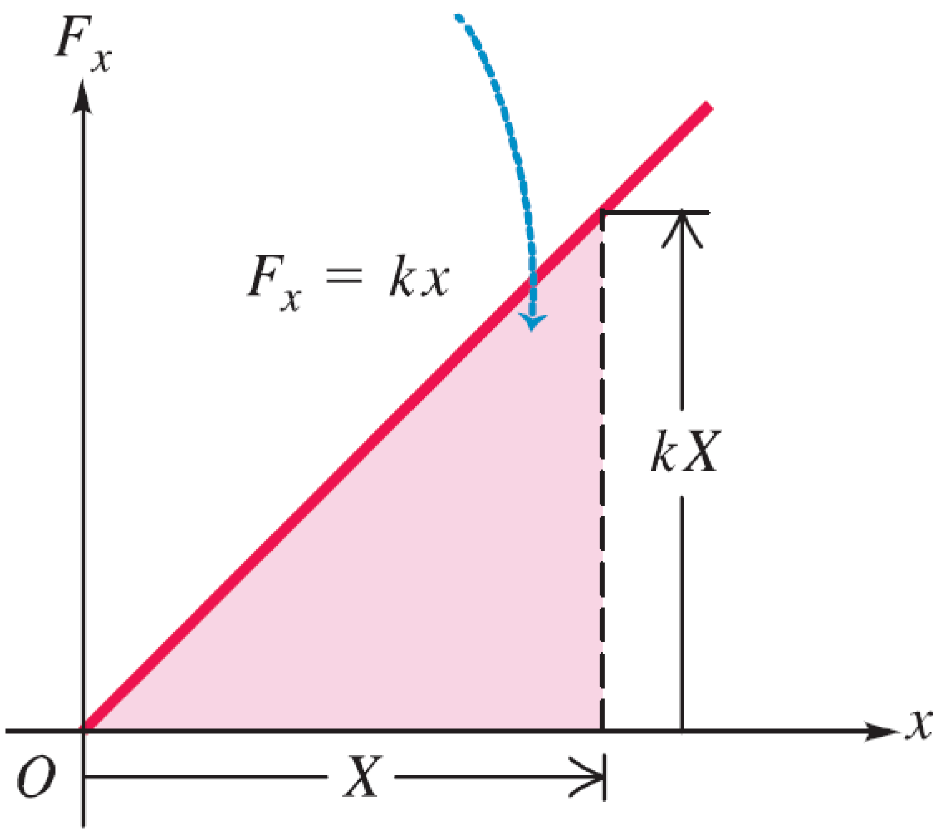
The F-x graph is a straight line (Hooke's law).

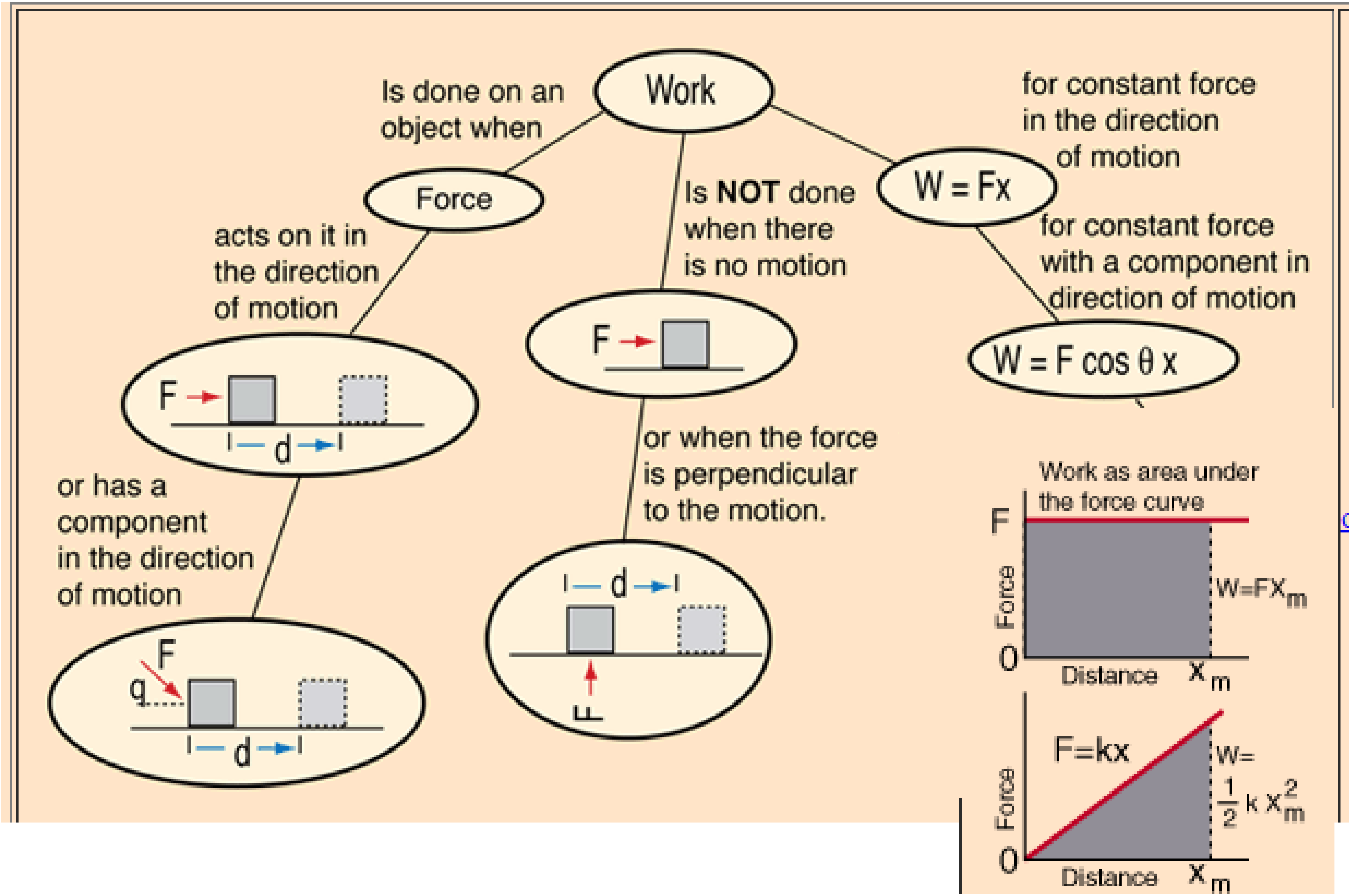
$$\boldsymbol{F = kx}$$

The work done by the stretching force is still the area under the curve.

$$WD = \frac{1}{2}kx^2$$

Work done by ***F*** to stretch spring




Work
Is done on an object when
Force
acts on it in the direction of motion
F
d
or has a component in the direction of motion
F
q
d
Is NOT done when there is no motion
F
or when the force is perpendicular to the motion.
d
F
W = Fx
for constant force in the direction of motion
for constant force with a component in direction of motion
W = F cos θ x
Work as area under the force curve
F
Force
0
Distance
X m
W=FXm
F=kx
W= 1/2 k X m 2

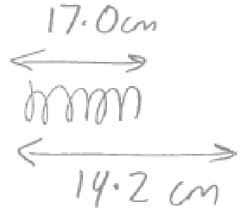
Another example

- An unstretched spring is 17.0 cm long. When a force of 25.0 N stretches it, its length increases to 19.2 cm.

(a) What is the force or spring constant (k) ?

(b) How much work was required to stretch the spring from 17.0 cm to 19.2 cm?

ANS a) 1136 N/m   b) 0.275 J



$F = 25.0\ N$

(a) $k = ?$ $\quad x$ = extension

$= 2.2\ cm$

$= 0.022\ m$

$F = kx \qquad k = \dfrac{F}{x} = \dfrac{25.0}{0.022}$

$= 1136\ N/m$

(b) $WD = \frac{1}{2} k x^2$

$= \frac{1}{2}\, 1136\, (0.022)^2$

$= 0.275\ J$

Energy Essentials (2)

Conservation of <u>Mechanical</u> Energy

- The <u>TOTAL</u> mechanical energy in an <u>ISOLATED SYSTEM</u> remains <u>CONSTANT</u> (conserved) no matter what happens in the system.

$$Initial\ total\ mech.energy = final\ total\ mech.energy$$

$$E_i = E_f$$

$$K_i + U_{gi} + U_{ei} = K_f + U_{gf} + U_{ef}$$

Dissipation of mechanical energy

- **When dissipative forces act on a system, mechanical energy is no longer conserved.**
- **Dissipative force "waste" mechanical energy as internal energy.**
- **Friction and air drag (resistance) are examples of dissipative forces.**
- **In this case TOTAL ENERGY IS CONSERVED.**
  - $\boldsymbol{Initial\ TOTAL\ energy = Final\ TOTAL\ energy}$

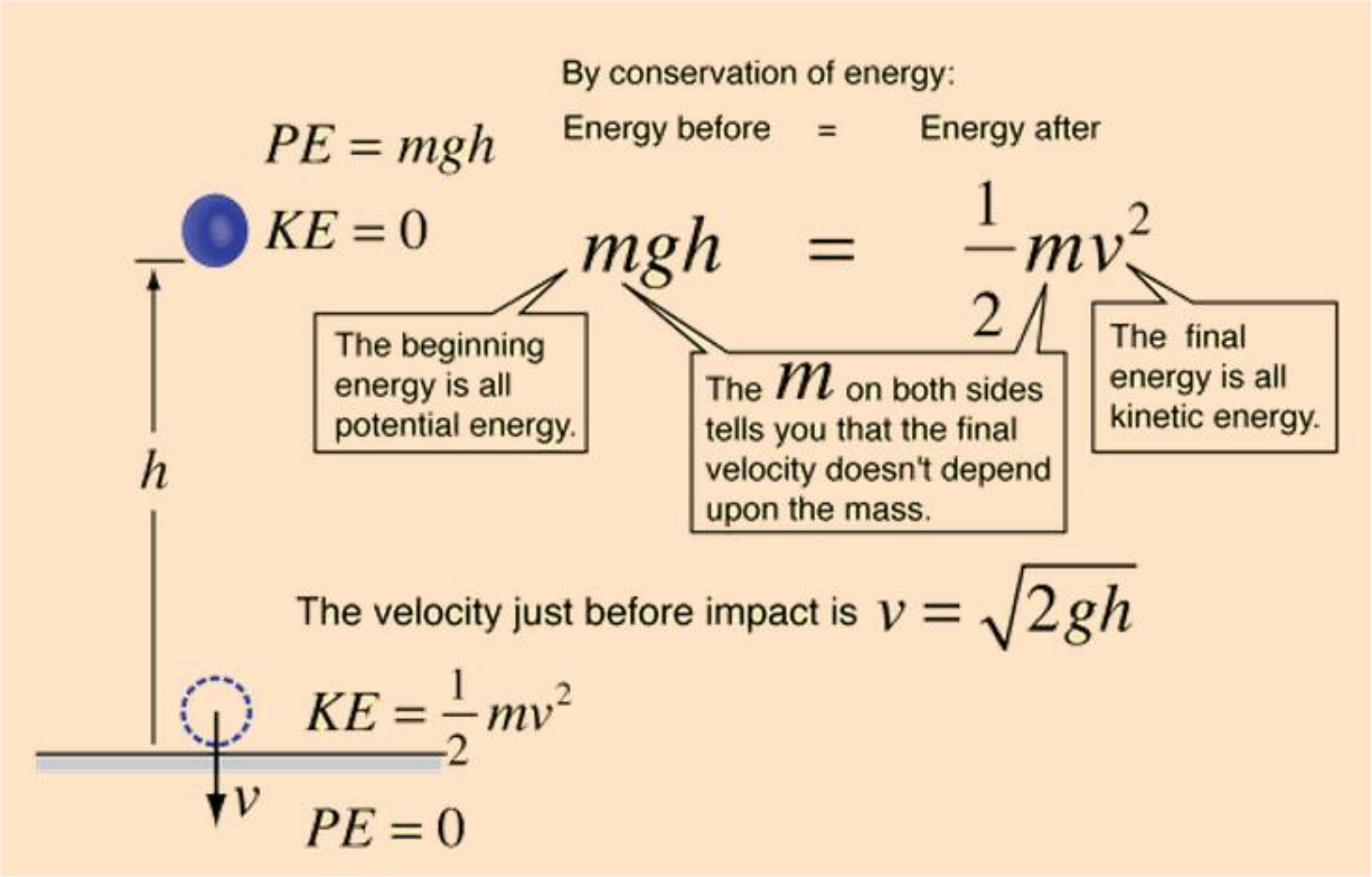
$$\sum E_i = \sum E_f$$

VTD Chin Basher?

VTD Work and Kinetic energy.

PhET The ramp

Like VTS Ex 7.7



$$\sum E_i = \sum E_f$$

Conservation of MECH. Energy

- Example (based on problem 42)
- If air drag is negligibly small, how fast is a 100-g sequoia cone moving when it reaches the ground if it dropped from the top of a 100 m tree?

ANS 44.3 m/s

$$\sum E_i = \sum E_f$$

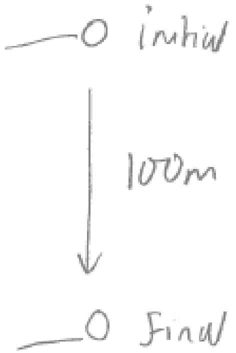
$$100\ g \ \frac{1\ kg}{1000\ g} = 0.1\ kg$$

Conservation of energy

$$\sum E_i = \sum E_f$$

$$K_i + U_{gi} + U_{ei} = K_f + U_{gf} + U_{ef}$$

$$0 + mgy + 0 = \frac{1}{2}mv^2 + 0 + 0$$



$$\cancel{m}gy = \frac{1}{2}\cancel{m}v^2$$

$$v = \sqrt{2gy}$$

$$= \sqrt{2\ 9.8\ 100}$$

$$= 44.3\ m/s$$

Dissipation of mechanical energy

- Example (based on problem 42)
- How fast is a 100-g sequoia cone moving when it reaches the ground if it dropped from the top of a 100 m tree? Air drag takes away 22 J of energy as the cone falls the 100 m.

ANS 39.0 m/s

$$\sum E_i = \sum E_f$$

lost energy

m = 0.1 kg

$$K_i + U_{gi} + U_{ei} - 22\,J = K_f + U_{gf} + U_{ef}$$

$$0 + mgy + 0 - 22 = \frac{1}{2}mv^2 + 0 + 0$$

$$mgy - 22 = \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{2}{m}(mgy - 22)}$$

m does **NOT** cancel

$$= \sqrt{\frac{2}{0.1}\left(0.1(9.8)100 - 22\right)}$$

$$= 39.0 \text{ m/s}$$

MUST BE LESS THAN 44.3 m/s

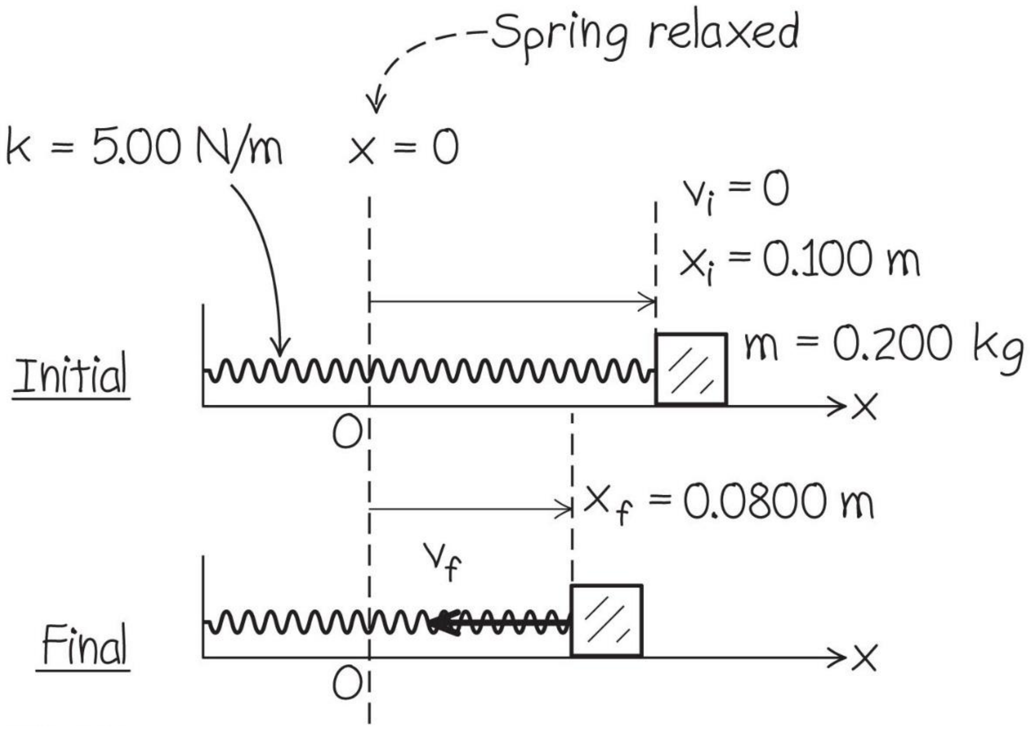
You loose 22J of energy so there is 22J of energy less at the end

Potential Energy on an Air Track with Mass and Spring

- Refer to Example 7.8.
- Knowing the initial state of our system and thus the total mechanical energy, we use this to find the final state at any position.
- Using conservation of total mechanical energy:

$$K_\mathrm{i} + U_\mathrm{i} = K_\mathrm{f} + U_\mathrm{f}$$

$$\tfrac{1}{2}mv_\mathrm{i}^2 + \tfrac{1}{2}kx_\mathrm{i}^2 = \tfrac{1}{2}mv_\mathrm{f}^2 + \tfrac{1}{2}kx_\mathrm{f}^2$$



VTS Ex 7.8

Work-energy theorem

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

Work-Energy Principle

$$W_{net} = \frac{1}{2} mv^2_{final} - \frac{1}{2} mv^2_{initial}$$

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

Work-energy theorem

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

- Example
- A $1.2\text{x}10^3$-kg car accelerates from 20.0 m/s to 24.0 m/s

- (a) Assuming (!) no significant energy losses, find the work done by the engine.
- (b) It was found that friction and air drag cause an energy loss of 24 kJ. What was the actual (total) work done by the engine if the same car still accelerates from 20.0 m/s to 24.0 m/s.

ANS a) 105600 J

$$\boxed{W = \Delta KE}$$

m 1.2×10^3 Kg car

$V_0 = 20.0\, m/s$

$V_f = 24.0\, m/s$

(a)

$$W = \Delta KE$$

$$= \frac{1}{2} m \left(V_f^2 - V_i^2\right)$$

$$= \frac{1}{2}\, 1.2 \times 10^3 \left(24^2 - 20^2\right)$$

$$= 105600 \text{ J}$$

(b) Engine has to overcome friction so needs to do more work

$$W = 105{,}600 + 24{,}000$$

$$= 124600 \text{ J}$$

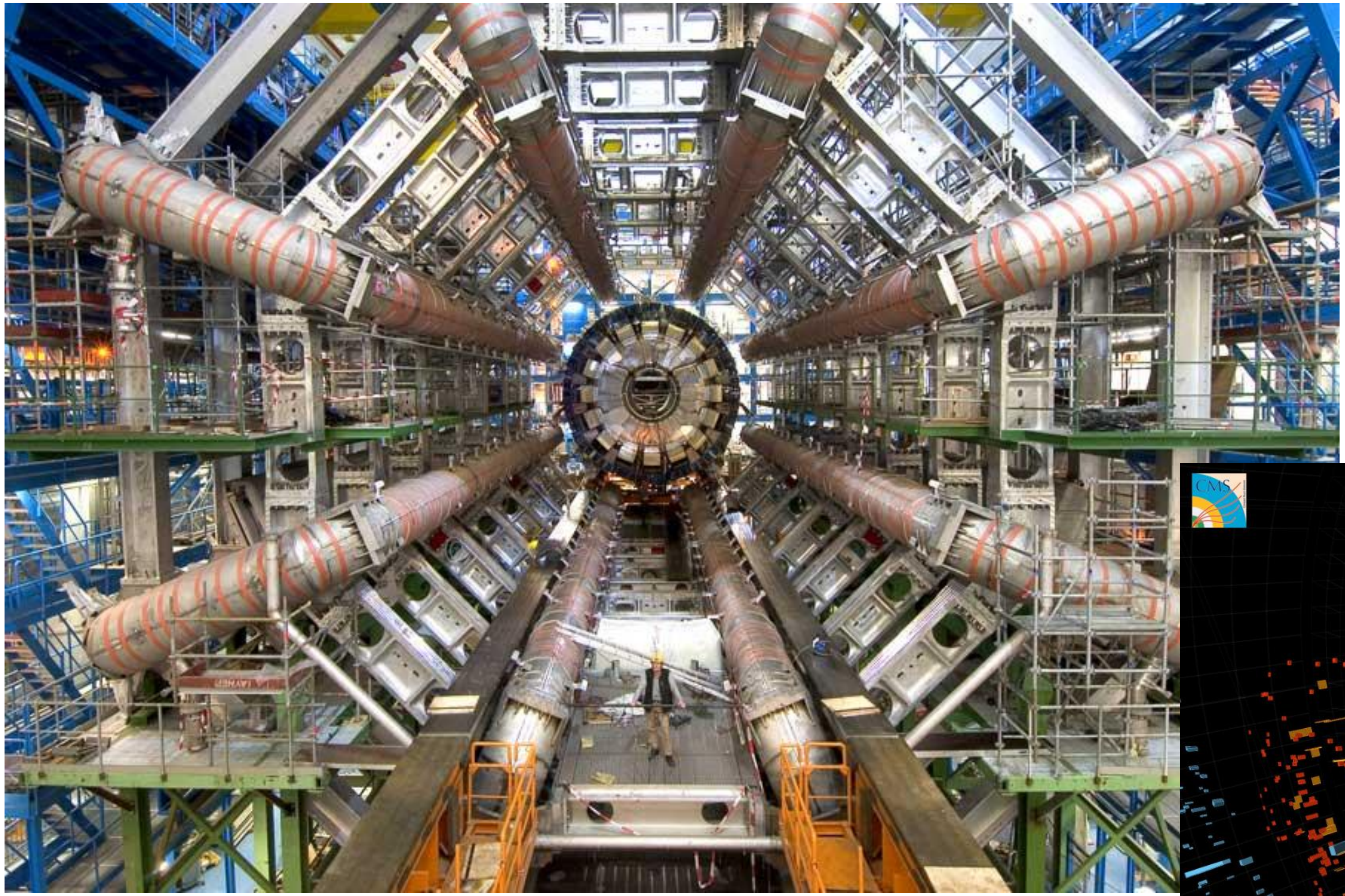
• A bullet is fired into a large stationary absorber and comes to rest. Temperature measurements of the absorber show that the bullet lost 1960 J of kinetic energy, and high-speed photos of the bullet show that it was moving at 965 m/s just as it struck the absorber. What is the mass of the bullet?

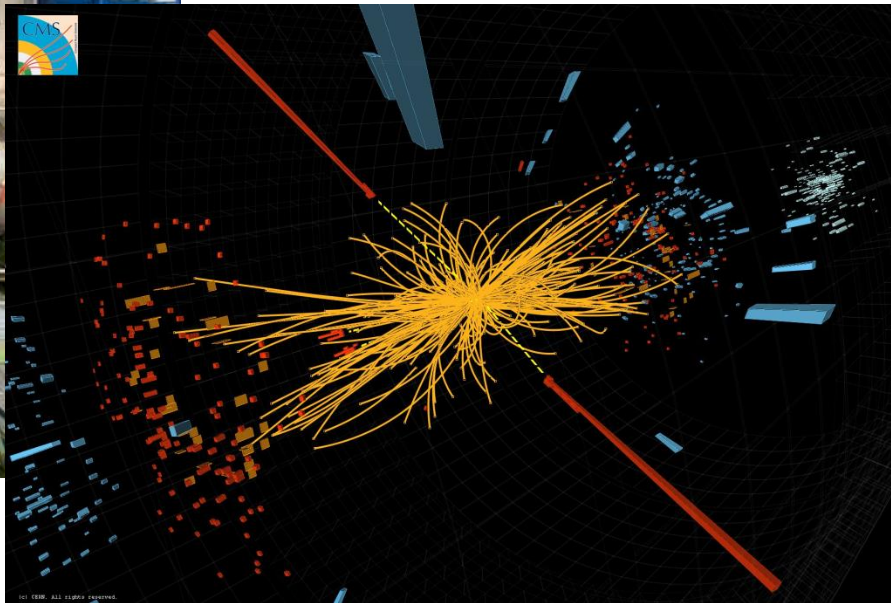
***7.13. Set Up:** Use $K = \frac{1}{2}mv^2$ and solve for m.

Solve: $m = 2K/v^2 = 2(1960 \text{ J})/(965 \text{ m/s})^2 = 4.21\times10^{-3} \text{ kg} = 4.21 \text{ g}$

Reflect: The kinetic energy of an object is proportional to the mass of the object.

The LHC uses calorimeters to measure the energy loss of particles





7.4 Work Done by a Varying Force

25. • To stretch a certain spring by 2.5 cm from its equilibrium position requires 8.0 J of work. (a) What is the force constant of this spring? (b) What was the maximum force required to stretch it by that distance?

***7.25. Set Up:** Use $W_{\text{on spring}} = +\frac{1}{2}kx^2$ in part (a) and $F_{\text{on spring}} = kx$ in part (b).

Solve: (a) $k = \dfrac{2(W_{\text{on spring}})}{x^2} = \dfrac{2(8.0\text{ J})}{(0.025\text{ m})^2} = 2.6\times10^4\text{ N/m}.$

Power

Power is the rate of doing work.

Average power $$P_{av} = \frac{W}{\Delta t}$$

Example

A car uses 6000 J of energy in 9.1 s. Calculate the average power developed by its engine.

Power – Considers Work and Time to do It

- When a quantity of work ΔW is done during a time interval Δt, the average power P_{av} or work per unit time is:

$$P_{\text{av}} = \frac{\Delta W}{\Delta t}$$

- Units of watt [W], or 1 watt = 1 joule per second [J/s]
- The rate at which work is done is not always constant. When it varies, we define the instantaneous power P as:

$$P = \lim_{\Delta t \to 0} \frac{\Delta W}{\Delta t} = F_{\parallel} v$$

$$P = \frac{W}{t} = \frac{Fs}{t} = Fv$$

Power – Considers Work and Time to do It

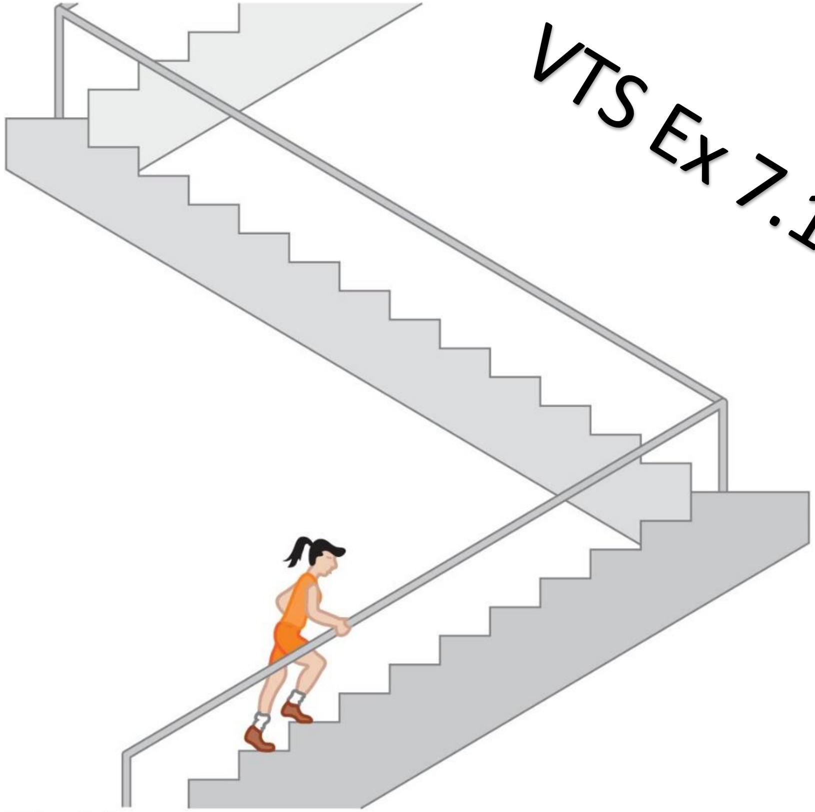
- Example 7.16: A marathon stair climb
- If the runner is initially at rest and ends at rest, the work done by the runner is equal to the work done by gravity on the run

$$W_{runner} = mgh$$

- The average power output by the ru

$$P_{av} = \frac{W_{runner}}{\Delta t} = \frac{mgh}{\Delta t}$$

$$= F\upsilon_{av} = mg\upsilon_{av}$$



VTS Ex 7.16

Use answer from (a)

7.8 Power

63. • (a) How many joules of energy does a 100 watt lightbulb use every hour? (b) How fast would a 70 kg person have to run to have that amount of kinetic energy? Is it possible for a person to run that fast? (c) How high a tree would a 70 kg person have to climb to increase his gravitational potential energy relative to the ground by that amount? Are there any trees that tall?

64. • The engine of a motorboat delivers 30.0 kW to the propeller while the boat is moving at 15.0 m/s. What would be the tension in the towline if the boat were being towed at the same speed?

$$KE = \frac{1}{2}mv^2 \qquad U_g = mgy \qquad P = \frac{W}{t} = Fv$$

***7.63. Set Up:** For part (a) use $P = \dfrac{W}{\Delta t}$ to solve for W, the energy the bulb uses. Then set this value equal to $\frac{1}{2}mv^2$ for part (b), and solve for the speed. In part (c), equate the W from part (a) to $U_{\text{grav}} = mgh$ and solve for the height.

Solve: **(a)** $W = P\,\Delta t = (100\text{ W})(3600\text{ s}) = 3.6\times10^5\text{ J}$

(b) $K = 3.6\times10^5\text{ J}$ so $v = \sqrt{\dfrac{2K}{m}} = \sqrt{\dfrac{2(3.6\times10^5\text{ J})}{70\text{ kg}}} = 100\text{ m/s}$

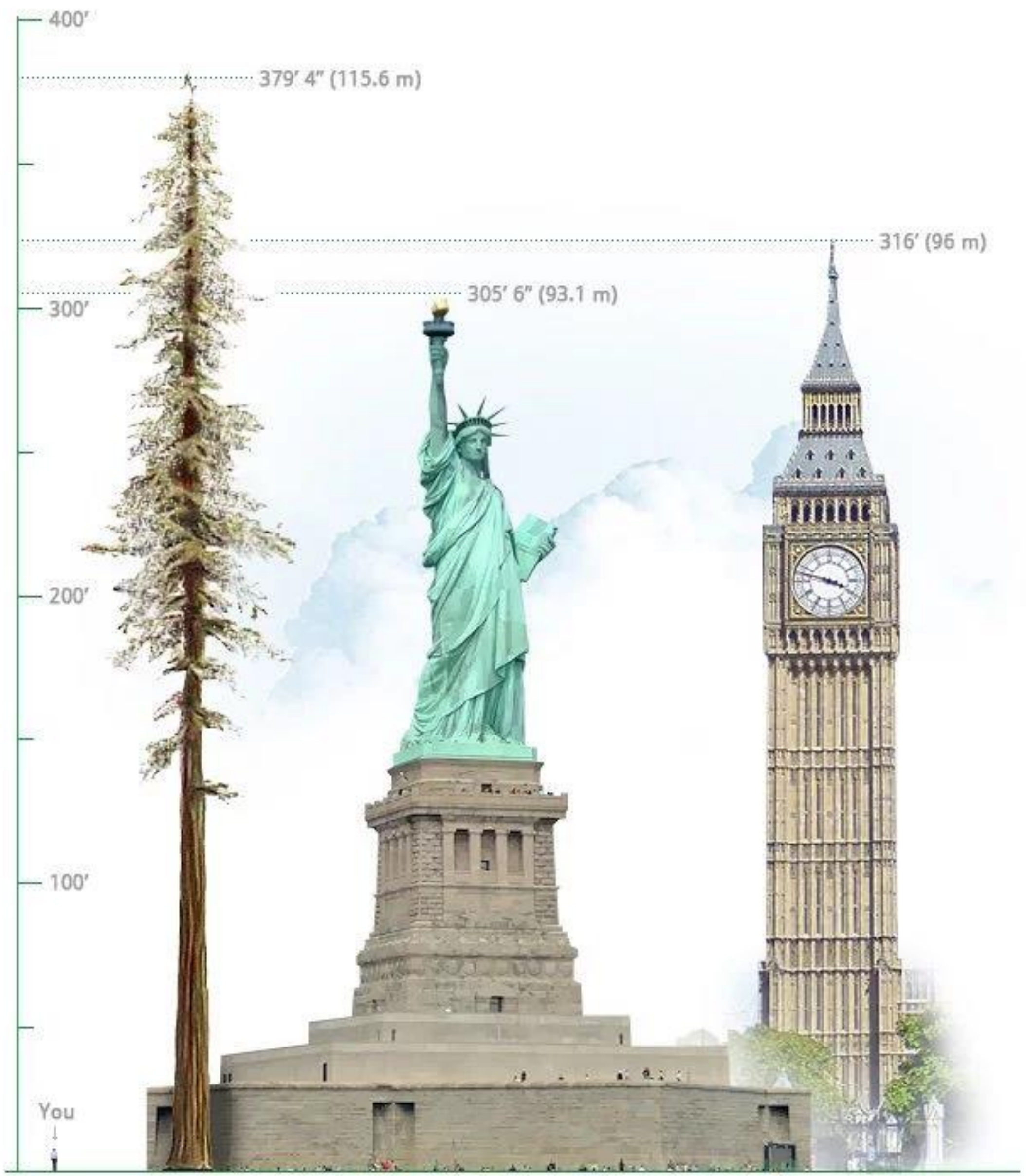
(c) $U_{\text{grav}} = 3.6\times10^5\text{ J}$ so $h = \dfrac{U_{\text{grav}}}{mg} = \dfrac{3.6\times10^5\text{ J}}{(70\text{ kg})(9.80\text{ m/s}^2)} = 520\text{ m}$

Reflect: **(b)** Olympic runners achieve speeds up to approximately 36 m/s, or roughly one = third the result calculated. **(c)** The tallest tree on record, a redwood, stands 364 ft or 110 m, or 4.7 times smaller than the result.

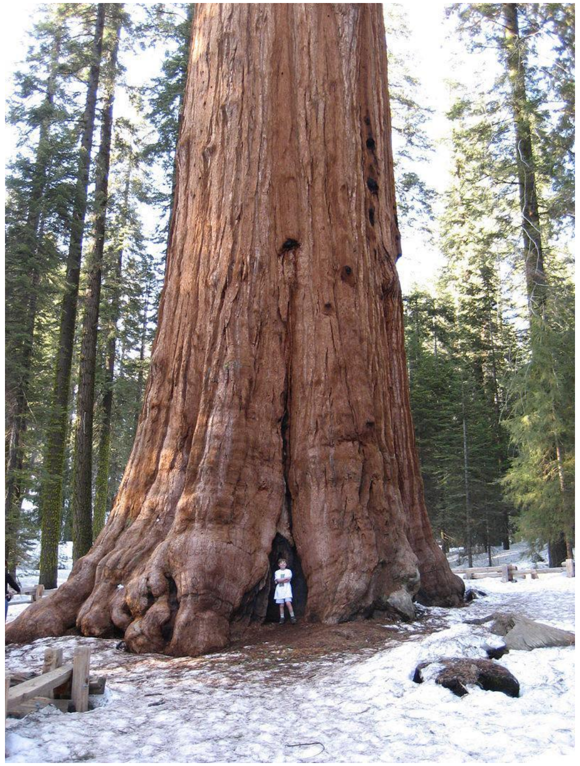
7.64. Set Up: Use the relation $P = Fv$ to relate the given power and velocity to the force required. Recall that a watt represents the rate of energy—a joule per second.

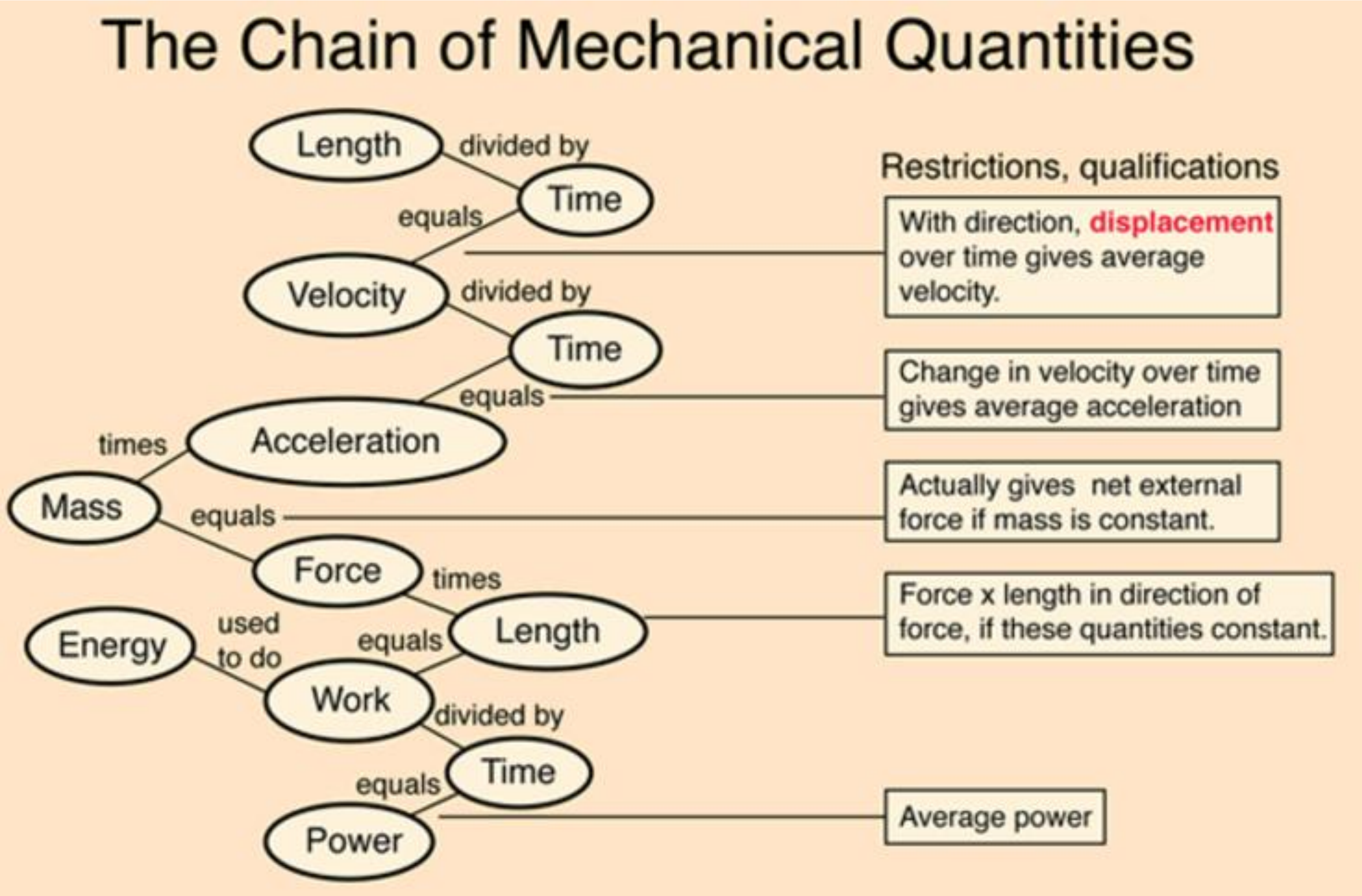
Solve: The force required is thus $F = (30.0\times10^3\text{ J/s})/(15.0\text{ m/s}) = 2.00\times10^3\text{ N}.$

Fastest human 45 km/hr = 12.5 m/s

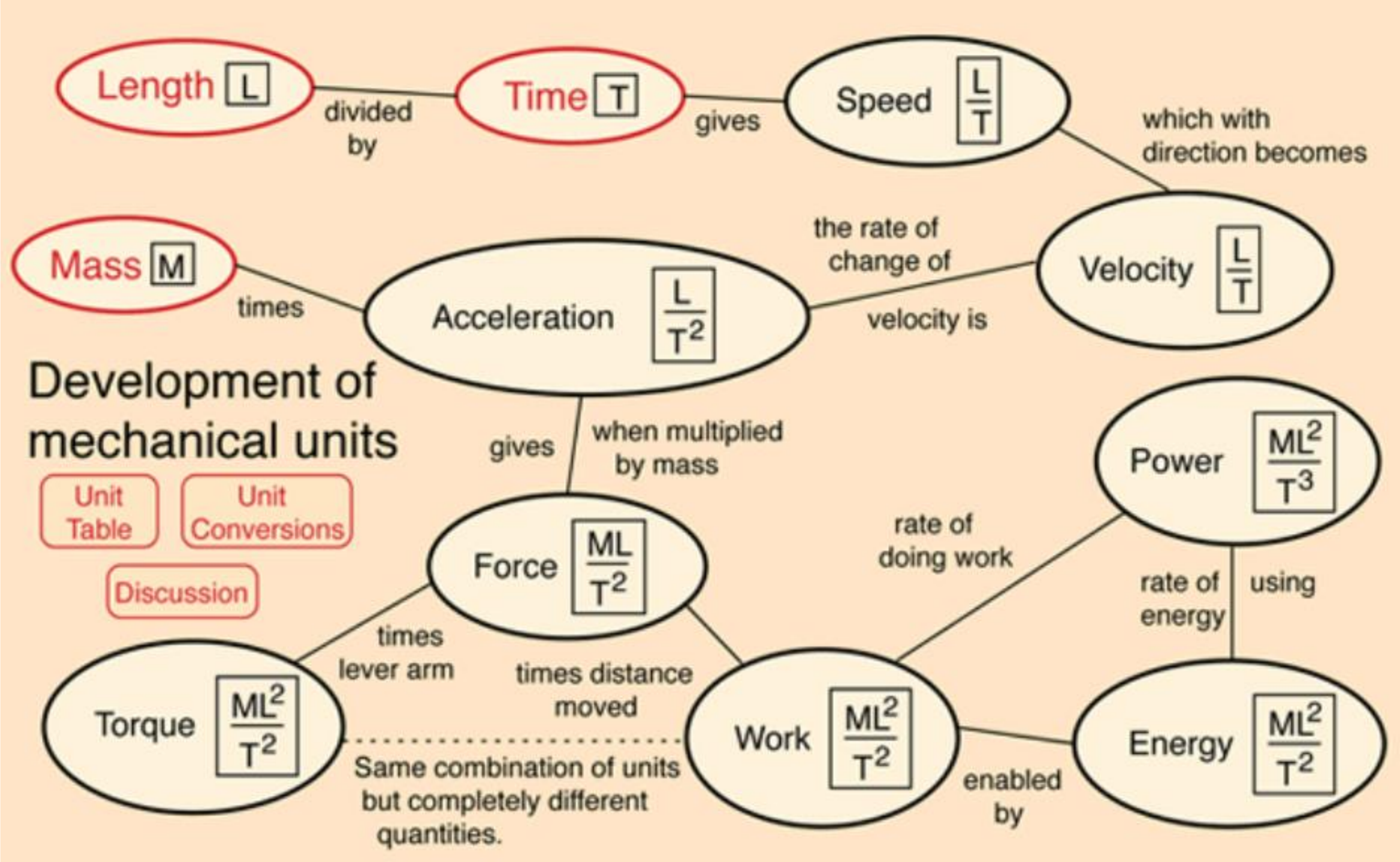


Height comparison of the Hyperion tree (iltwmt.com)





$Note\colon\ Power\ is\ measured\ in\ Watts\ or\ kg\ \frac{m^2}{s^3}$



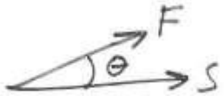
Length L
divided by
Time T
gives
Speed L/T
which with direction becomes
Velocity L/T
the rate of change of velocity is
Mass M
times
Acceleration L/T2
Development of mechanical units
Unit Table
Unit Conversions
Discussion
gives
when multiplied by mass
Force ML/T2
rate of doing work
Power ML2/T3
rate of energy
using
times lever arm
times distance moved
Torque ML2/T2
Work ML2/T2
Energy ML2/T2
enabled by
Same combination of units but completely different quantities.

Summary

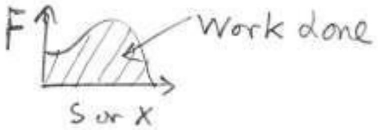
Work, energy & power (CLO5, Chapter 7)

- Work done is energy transferred.
- Total energy is always conserved.

$W = F_{\parallel} s = (F\cos\theta)s$



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



$F = kx$

Work Energy + Power

POTENTIAL

$U_g = mgy$

$U_e = \frac{1}{2}kx^2$

CONSERVATION

$\boxed{K_i + U_{g_i} + U_{e_i} = K_f + U_{g_f} + U_{e_f}}$

$P = \frac{\Delta W}{\Delta t}$

$\boxed{W = \Delta E}$

$W = \Delta K$

7

Use the textbook for more details

VTD Chin Basher?

VTS Ex 7.1

PhET The ramp

Sears & Zemansky's
College Physics
TENTH EDITION
Young • Adams • Chastain

STUDY AREA

Chapter 7: Work and Energy

Home > Chapter 7: Work and Energy > Chapter 7 Assets

Chapter 7 Assets

Video Tutor Demonstrations

PhET Simulations

eText

Chapter 7 Assets

Video Tutor Demonstrations

- Chin Basher?
- Work and Kinetic Energy

Video Tutor Solutions

- Example 7.1 Pushing a stalled car
- Example 7.2 Sliding down a ramp
- Example 7.3 Work done by several forces
- Example 7.4 Using work and energy to calculate speed
- Example 7.5 Forces on a hammerhead
- Example 7.6 Work done on a spring scale
- Example 7.7 Height of a baseball from energy conservation
- Example 7.8 Potential energy on an air track
- Example 7.9 Maximum height of a home-run ball
- Example 7.10 Calculating speed along a vertical circle
- Example 7.11 Elevator safety (or not)
- Example 7.12 Work and energy on an air track
- Example 7.13 Skateboarder on the quarter-pipe again
- Example 7.14 Loading a crate onto a truck
- Example 7.15 Power in a jet engine
- Example 7.16 A marathon stair climb
- Chapter 7 Bridging Problem

PhET Simulations

- The Ramp

Appendix

Extra info
More examples

Use textbook for more information

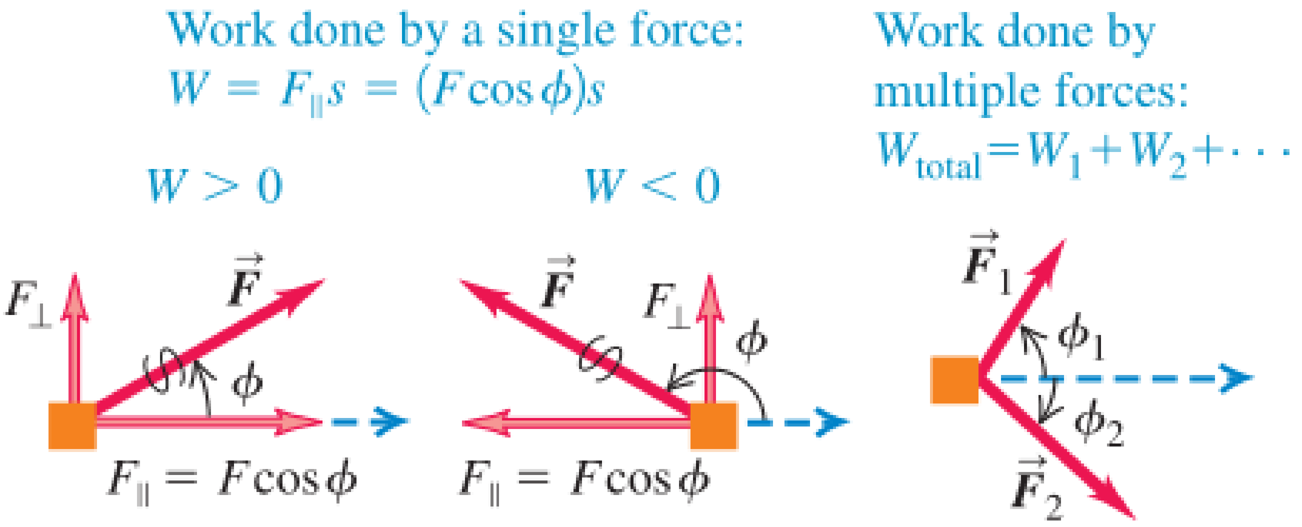
SUMMARY

Overview of Energy

(Section 7.1) Energy is one of the most important unifying concepts in all of physical science. Its importance stems from the principle of conservation of energy. Energy is exchanged and transformed during interactions of systems, but the total energy in a closed system is constant. This chapter is concerned with mechanical energy of three types: kinetic energy, associated with the motion of objects that have mass; gravitational potential energy, associated with gravitational interactions; and elastic potential energy, associated with elastic deformations of objects. Potential energy can be viewed as a stored quantity that represents the potential for doing work.

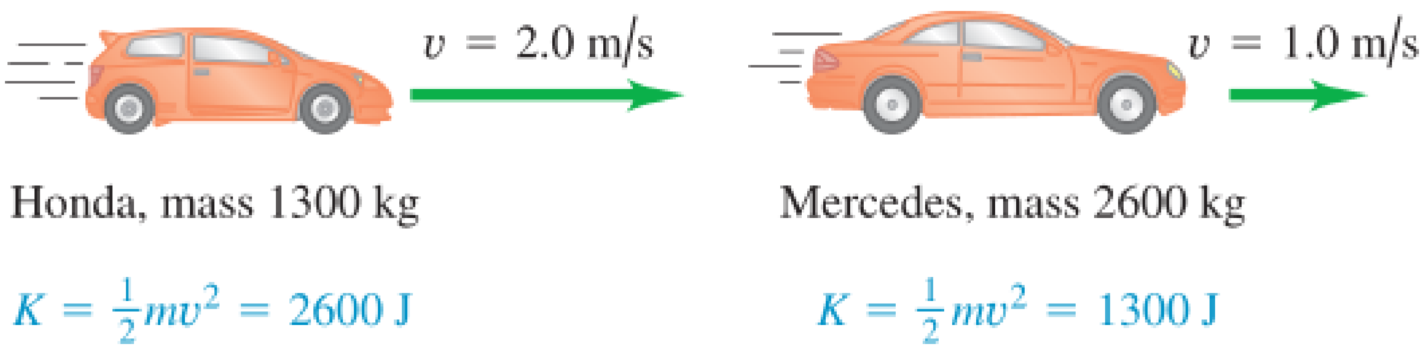
Work

(Section 7.2) When a force acts on an object that undergoes a displacement, the force does work on the object and transfers energy to it. For a constant force, $W = F_{\parallel}s$ (Equation 7.1), where $F_{\parallel}$ is the component of force parallel to the object's displacement (of magnitude s). This component can be positive, negative, or zero. Work is a scalar quantity, not a vector. If $F_{\parallel}$ points opposite to the displacement, then $W < 0$. When several forces act on an object, the total work done by all the forces is the sum of the amounts of work done by the individual forces.



Work and Kinetic Energy

(Section 7.3) The kinetic energy K of an object is defined in terms of the object's mass m and speed v as $K = \frac{1}{2}mv^2$. When forces act on an object, the change in its kinetic energy is equal to the total work done by all the forces acting on it: $W_{\text{total}} = K_f - K_i = \Delta K$ (Equation 7.4). When W is positive, the object speeds up; when W is negative, it slows down.



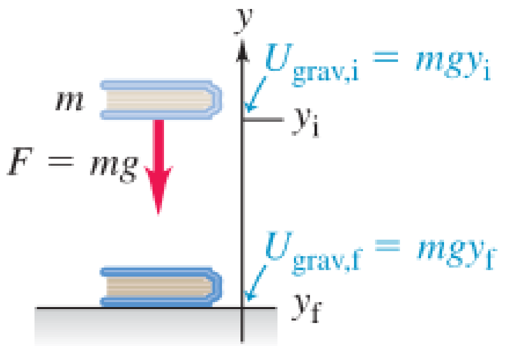
Work Done by a Varying Force

(Section 7.4) When an object moves under the action of a varying force parallel to the displacement, the work done by the force is represented graphically as the area under a graph of the force as a function of displacement. If the magnitude of force F required to stretch a spring a distance x beyond its natural length is proportional to x, then $F = kx$, where k is a constant for the spring, called its force constant or spring constant. The total work W needed to stretch the spring from $x = 0$ to $x = X$ is $W = \frac{1}{2}kX^2$.

Area

Potential Energy

(Section 7.5) Potential energy can be thought of as *stored* energy. For an object with mass m at a height y above a chosen origin (where $y = 0$), the gravitational potential energy is $U_{grav} = mgy$ (Equation 7.9). When a spring is stretched or compressed a distance x from its uncompressed length, the spring stores elastic potential energy $U_{el} = \frac{1}{2}kx^2$ (Equation 7.13). Potential energy is associated only with conservative forces, not with nonconservative forces such as friction.

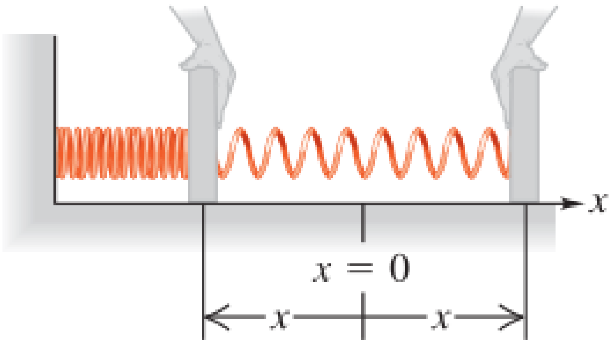


Gravitational potential energy: For an object at vertical position y,

$$U_{grav} = mgy$$

For a change in vertical position,

$$\Delta U_{grav} = U_{grav,f} - U_{grav,i}$$

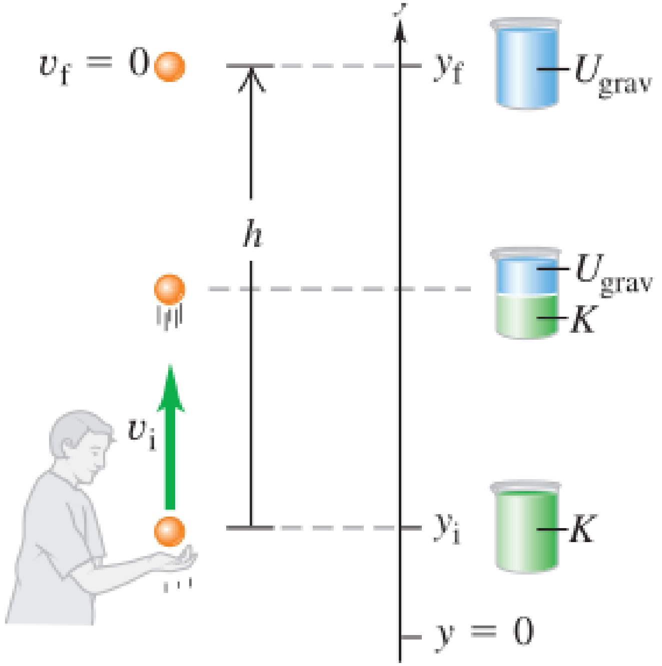


Elastic potential energy: For a spring stretched or compressed by a distance x from equilibrium,

$$U_{el} = \frac{1}{2}kx^2$$

Conservation of Energy

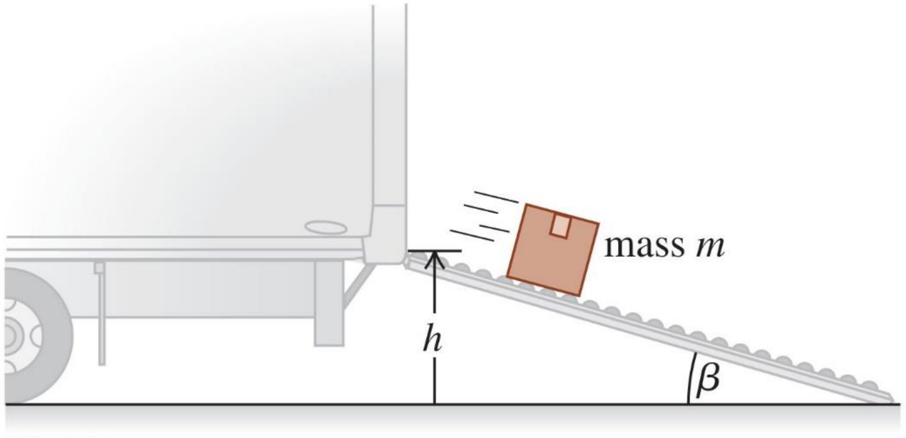
(Sections 7.6 and 7.7) When only conservative forces act on an object, the total mechanical energy (kinetic plus potential) is constant; that is, $K_i + U_i = K_f + U_f$, where U may include both gravitational and elastic potential energies. If some of the forces are nonconservative, we label their work as W_{other}. The change in total energy (kinetic plus potential) of an object during any motion is equal to the work W_{other} done by the nonconservative forces: $K_i + U_i + W_{other} = K_f + U_f$ (Equation 7.16). Nonconservative forces include friction forces, which usually act to decrease the total mechanical energy of a system.



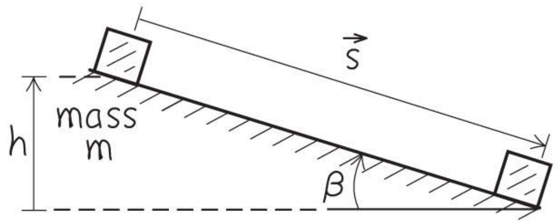
Power

(Section 7.8) Power is the time rate of doing work or the rate at which energy is transferred or transformed. For mechanical systems, power is the time rate at which work is done by or on an object or a system. When an amount of work ΔW is done during a time interval Δt, the average power is $P_{av} = \frac{\Delta W}{\Delta t}$ (Equation 7.17).

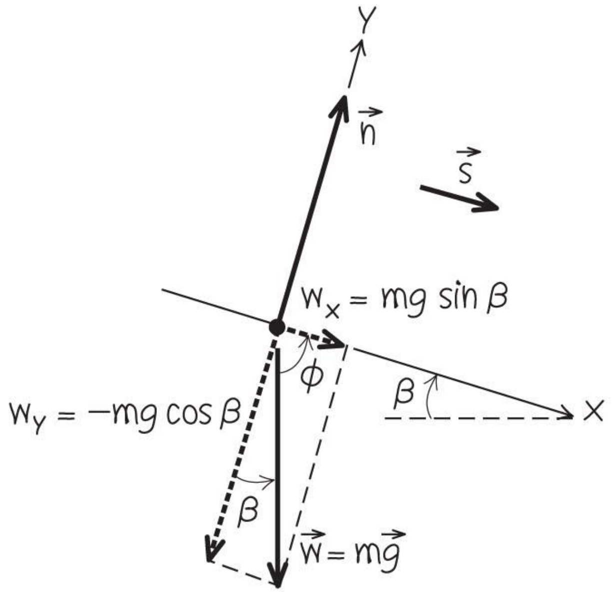
Sliding on a Ramp – Example 7.2



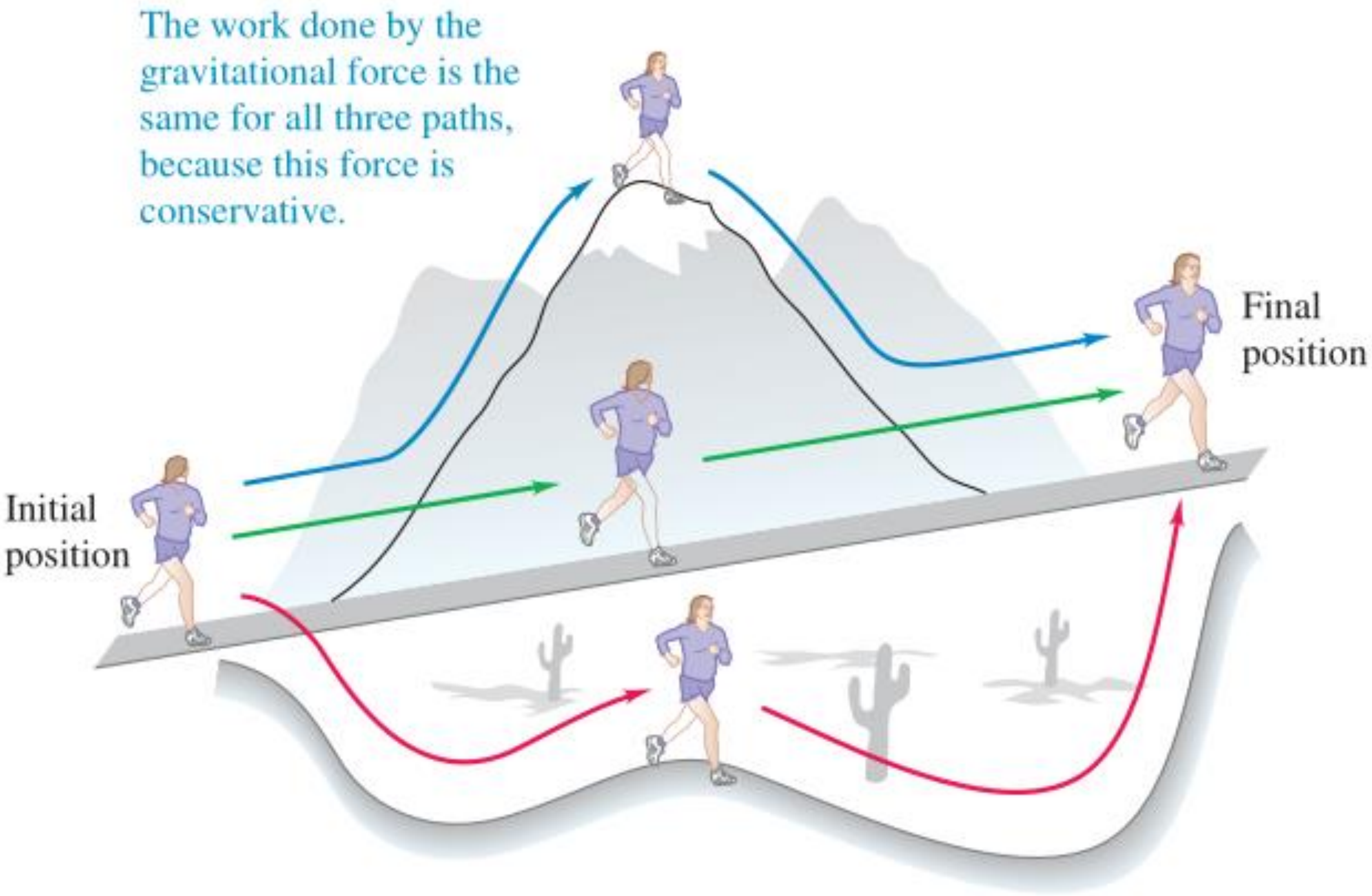
VTS Ex 7.2



(a) Sketch of situation



(b) Free-body diagram of package

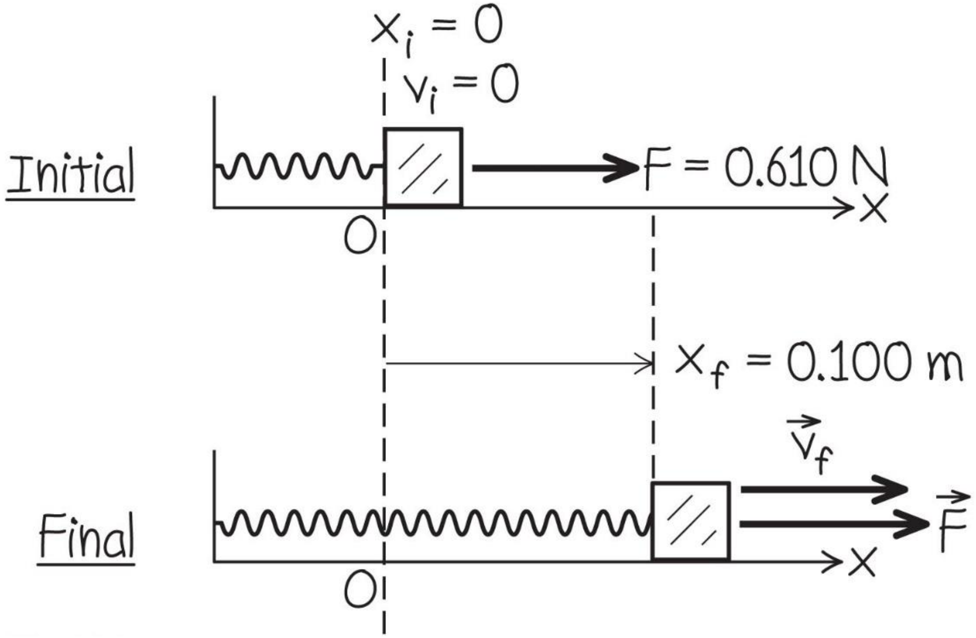


Conservative

Problems With Nonconservative Forces

- This is the same problem as Example 7.8, but now we also include the work done an external, a nonconservative force *F*.
- In addition to the spring force, there is a constant force *F* along the positive *x*-direction.

VTS Ex 7.12



$$W_{\mathrm{f}} = \left(K_{\mathrm{f}} + U_{\mathrm{f}}\right) - \left(K_{\mathrm{i}} + U_{\mathrm{i}}\right)$$

$$W_{\mathrm{f}} = \left(\tfrac{1}{2} m\upsilon_{\mathrm{f}}^2 + \tfrac{1}{2} kx_{\mathrm{f}}^2\right) - \left(\tfrac{1}{2} m\upsilon_{\mathrm{i}}^2 + \tfrac{1}{2} kx_{\mathrm{i}}^2\right)$$

$$\text{where } \; W_{\mathrm{f}} = Fx > 0$$

12. • It takes 4.186 J of energy to raise the temperature of 1.0 g of water by 1.0°C. (a) How fast would a 2.0 g cricket have to jump to have that much kinetic energy? (b) How fast would a 4.0 g cricket have to jump to have the same amount of kinetic energy?

7.12. Set Up: Use $K = \frac{1}{2}mv^2$ to calculate v, where K is equal to the change in thermal energy.

Solve: **(a)** $v = \sqrt{2K/m} = \sqrt{2(4.186\ \text{J})/(2.0\times 10^{-3}\ \text{kg})} = 65\ \text{m/s}$

(b) $v = \sqrt{2(4.186\ \text{J})/(4.0\times 10^{-3}\ \text{kg})} = 46\ \text{m/s}$

Reflect: When the mass increases by a factor of two, the speed required decreases by a factor of $1/\sqrt{2}$.