Properties of Matter

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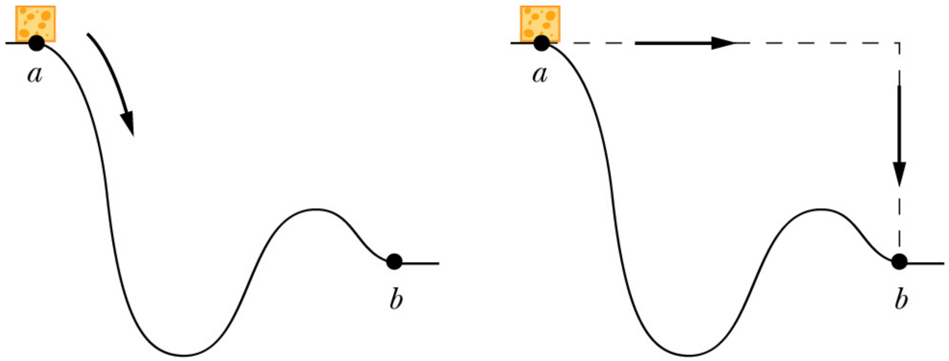
Energy

- Energy and Mechanical Energy
- Work
- Kinetic Energy
- Work and Kinetic Energy
- The Scalar Product of Two Vectors

Why Energy?

- Why do we need a concept of energy?
- The energy approach to describing motion is particularly useful when Newton's Laws are difficult or impossible to use
- Energy is a scalar quantity. It does not have a direction associated with it



What is Energy?

- Energy is a property of the state of a system, not a property of individual objects: we have to broaden our view.
- Some forms of energy:
  - Mechanical:
    - Kinetic energy (associated with motion, within system)
    - Potential energy (associated with position, within system)
  - Chemical
  - Electromagnetic
  - Nuclear
- Energy is conserved. It can be transferred from one object to another or change in form, but cannot be created or destroyed

Kinetic Energy

- Kinetic Energy is energy associated with the state of motion of an object
- For an object moving with a speed of $\boldsymbol{v}$

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

- SI unit: joule (J)

$$1 \text{ joule} = 1 \text{ J} = 1 \text{ kg m}^2/\text{s}^2$$

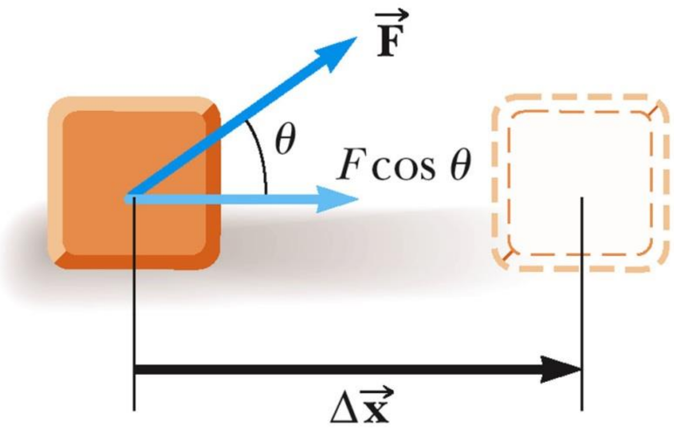
Work W

- Start with $$\frac{1}{2}mv^2 - \frac{1}{2}mv_0{}^2 = F_x \Delta x$$ Work “W”
- Work provides a link between force and energy
- Work done on an object is transferred to/from it
- If W > 0, energy added: “transferred to the object”
- If W < 0, energy taken away: “transferred from the object”

Definition of Work W

- The work, *W*, done by a constant force on an object is defined as the product of the component of the force along the direction of displacement and the magnitude of the displacement

$$W \equiv (F\cos\theta)\Delta x$$



  - F is the magnitude of the force
  - Δ x is the magnitude of the object's displacement
  - θ is the angle between $\vec{\mathbf{F}}$ and $\Delta\vec{\mathbf{x}}$

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Work Unit

- This gives no information about
  - the time it took for the displacement to occur
  - the velocity or acceleration of the object
- Work is a scalar quantity
- SI Unit
  - Newton • meter = Joule
    - N • m = J
    - J = kg • m^2 / s^2 = (kg • m / s^2) • m

$$\frac{1}{2}mv^2 - \frac{1}{2}mv_0{}^2 = (F\cos\theta)\Delta x$$

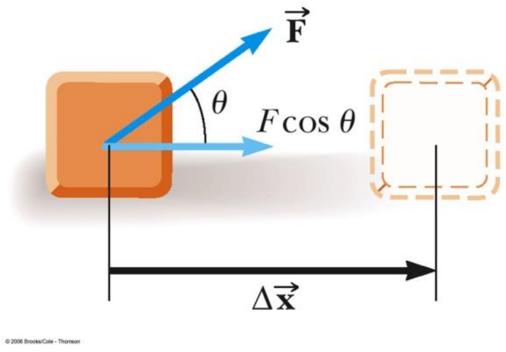
$$W \equiv (F\cos\theta)\Delta x$$

Work: + or -?

- Work can be positive, negative, or zero. The sign of the work depends on the direction of the force relative to the displacement

$$W \equiv (F\cos\theta)\Delta x$$

  - Work positive: W > 0 if 90° > θ > 0°
  - Work negative: W < 0 if 180° > θ > 90°
  - Work zero: W = 0 if θ = 90°
  - Work maximum if θ = 0°
  - Work minimum if θ = 180°



Example: When Work is Zero

- A man carries a bucket of water horizontally at constant velocity.
- The force does no work on the bucket
- Displacement is horizontal
- Force is vertical
- cos 90° = 0

$$W \equiv (F\cos\theta)\Delta x$$

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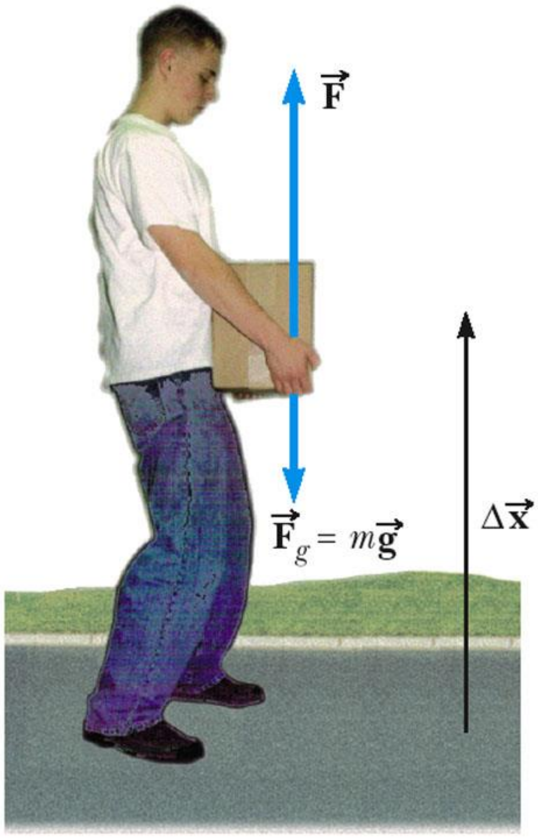
Example: Work Can Be Positive or Negative

- Work is positive when lifting the box
- Work would be negative if lowering the box
    - The force would still be upward, but the displacement would be downward



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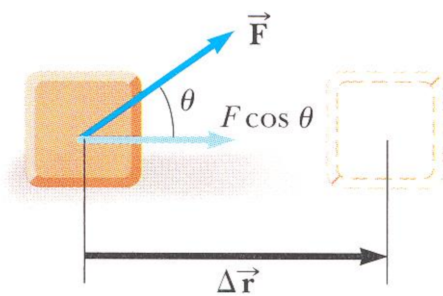
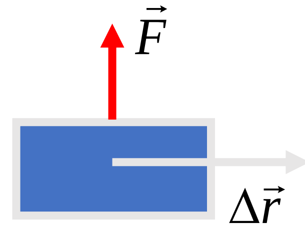
Work Done by a Constant Force

- The work W done on a system by an agent exerting a constant force on the system is the product of the magnitude F of the force, the magnitude Δr of the displacement of the point of application of the force, and cosθ, where θ is the angle between the force and displacement vectors:

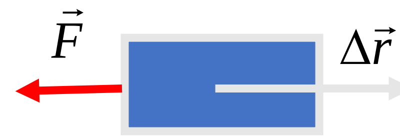
$$W \equiv \vec{F} \cdot \Delta\vec{r} = F\Delta r \cos\theta$$





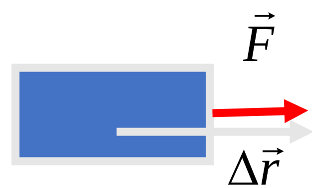
I

$$W_I = 0$$



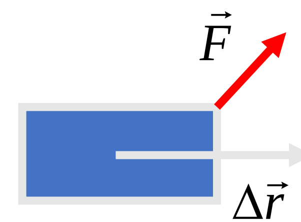
II

$$W_{II} = -F\Delta r$$



III

$$W_{III} = F\Delta r$$



IV

$$W_{IV} = F\Delta r\cos\theta$$

Calculate the work done by a force of 30 N in lifting a load of 2kg to a height of 10 m (g = 10 ms^{-2})

Answer:

Given : Force mg = 30 N ; height = 10 m

Work done to lift a load W = ?

W = F.S (or) mgh

= 30x10

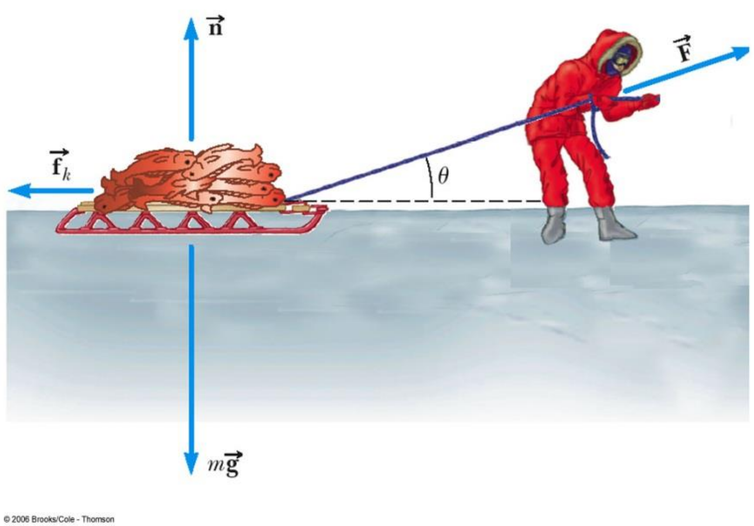
W = 300 J

Ans: 300J

Work and Force

- An Eskimo pulls a sled as shown. The total mass of the sled is 50.0 kg, and he exerts a force of 1.20 × 10^2 N on the sled by pulling on the rope. How much work does he do on the sled if θ = 30° and he pulls the sled 5.0 m ?

$$W = (F\cos\theta)\Delta x$$
$$= (1.20\times10^2\,N)(\cos 30^\circ)(5.0m)$$
$$= 5.2\times10^2\,J$$

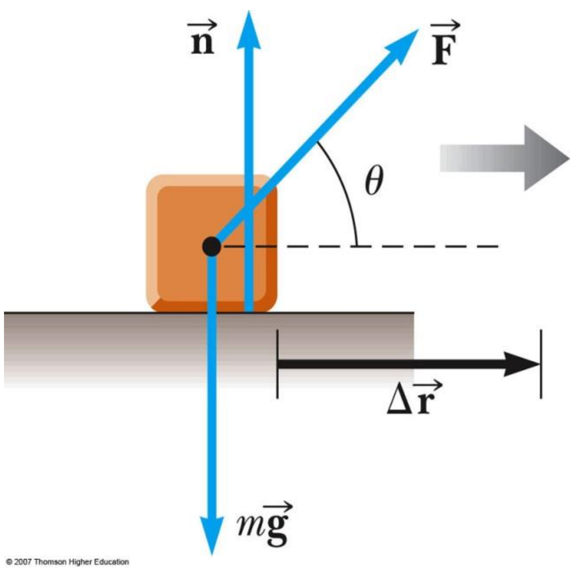


Work Done by Multiple Forces

- If more than one force acts on an object, then the total work is equal to the algebraic sum of the work done by the individual forces

$$W_{\text{net}} = \sum W_{\text{by individual forces}}$$

- Remember work is a scalar, so this is the algebraic sum

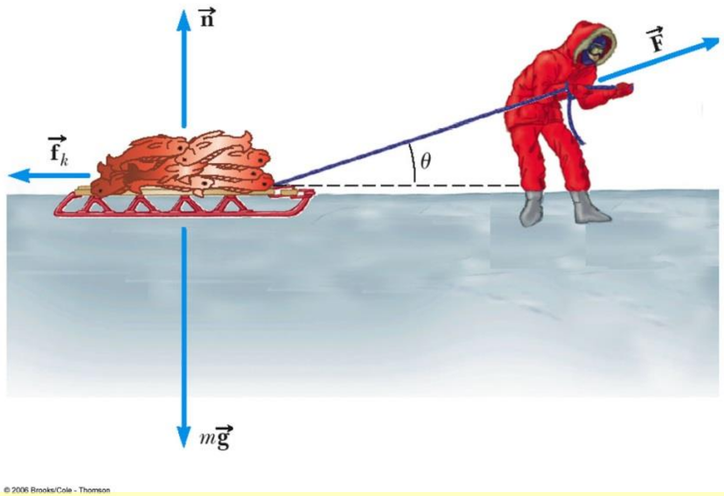


$$W_{net} = W_g + W_N + W_F = (F\cos\theta)\Delta r$$

Work and Multiple Forces

- Suppose μ_k = 0.200, How much work done on the sled by friction, and the net work if θ = 30° and he pulls the sled 5.0 m ?

$$F_{net,y} = N - mg + F\sin\theta = 0$$
$$N = mg - F\sin\theta$$



$$W_{fric} = (f_k \cos 180^\circ)\Delta x = -f_k \Delta x$$
$$= -\mu_k N \Delta x = -\mu_k (mg - F\sin\theta)\Delta x$$
$$= -(0.200)(50.0kg \cdot 9.8m/s^2$$
$$-1.2\times10^2 N \sin 30^\circ)(5.0m)$$
$$= -4.3\times10^2 J$$

$$W_{net} = W_F + W_{fric} + W_N + W_g$$
$$= 5.2\times10^2 J - 4.3\times10^2 J + 0 + 0$$
$$= 90.0 J$$

Kinetic Energy

- Kinetic energy associated with the motion of an object

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

- Scalar quantity with the same unit as work
- Work is related to kinetic energy

$$\frac{1}{2}mv^2 - \frac{1}{2}mv_0{}^2 = F_{net}\Delta x$$

$$W_{net} = KE_f - KE_i = \Delta KE$$

Work-Kinetic Energy Theorem

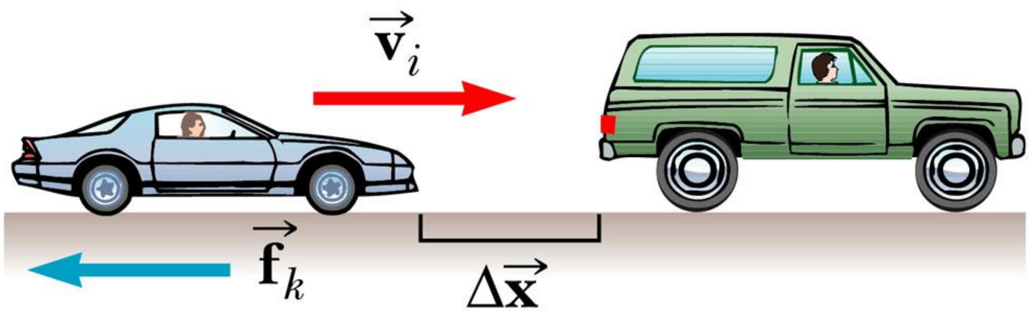
- When work is done by a net force on an object and the only change in the object is its speed, the work done is equal to the change in the object's kinetic energy
  - Speed will increase if work is positive
  - Speed will decrease if work is negative

$$W_{net} = KE_f - KE_i = \Delta KE$$

$$W_{net} = \frac{1}{2}mv^2 - \frac{1}{2}mv_0^{\ 2}$$

Work and Kinetic Energy

- The driver of a 1.00×10^3 kg car traveling on the interstate at 35.0 m/s slam on his brakes to avoid hitting a second vehicle in front of him, which had come to rest because of congestion ahead. After the breaks are applied, a constant friction force of 8.00×10^3 N acts on the car. Ignore air resistance. (a) At what minimum distance should the brakes be applied to avoid a collision with the other vehicle? (b) If the distance between the vehicles is initially only 30.0 m, at what speed would the collisions occur?



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Work and Kinetic Energy

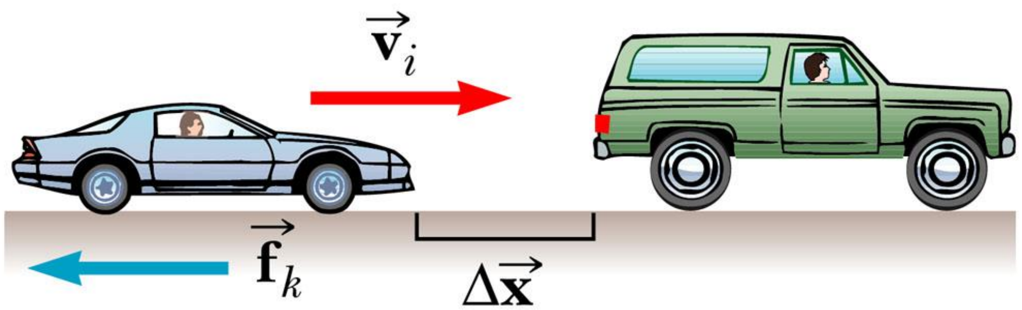
- (a) We know $v_0 = 35.0m/s, v = 0, m = 1.00\times10^3 kg,\ f_k = 8.00\times10^3 N$
- Find the minimum necessary stopping distance

$$W_{net} = W_{fric} + W_g + W_N = W_{fric} = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

$$-f_k\Delta x = 0 - \frac{1}{2}mv_0^2$$

$$-(8.00\times10^3 N)\Delta x = -\frac{1}{2}(1.00\times10^3 kg)(35.0m/s)^2$$

$$\Delta x = 76.6m$$



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Work and Kinetic Energy

- (b) We know $\Delta x = 30.0m, v_0 = 35.0m/s, m = 1.00\times 10^3 kg,\ f_k = 8.00\times 10^3 N$
- Find the speed at impact.
- Write down the work-energy theorem:

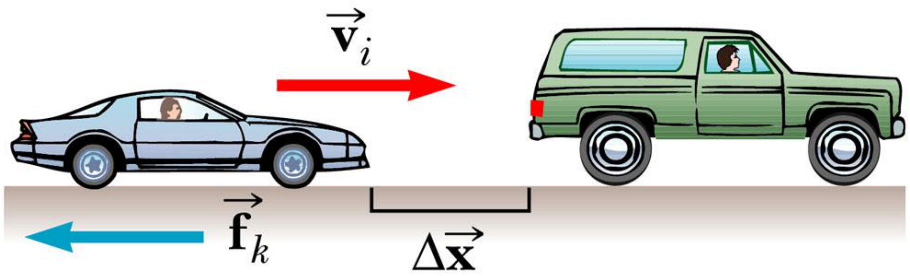
$v_0 = 35.0m/s, v = 0, m = 1.00\times 10^3 kg,\ f_k = 8.00\times 10^3 N$

$$W_{net} = W_{fric} = -f_k \Delta x = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

$$v_f^2 = v_0^2 - \frac{2}{m} f_k \Delta x$$

$$v_f^2 = (35m/s)^2 - (\frac{2}{1.00\times 10^3 kg})(8.00\times 10^3 N)(30m) = 745m^2/s^2$$

$$v_f = 27.3m/s$$



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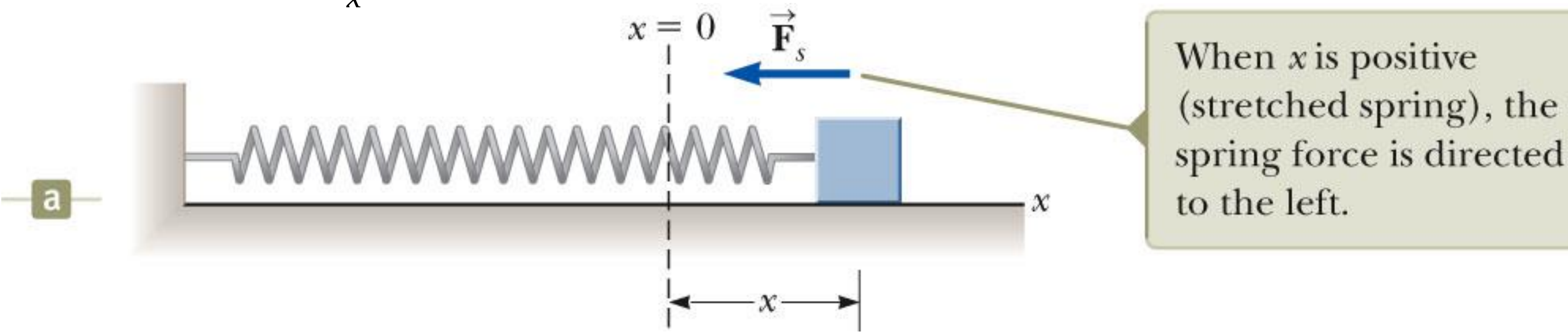
Work Done By a Spring

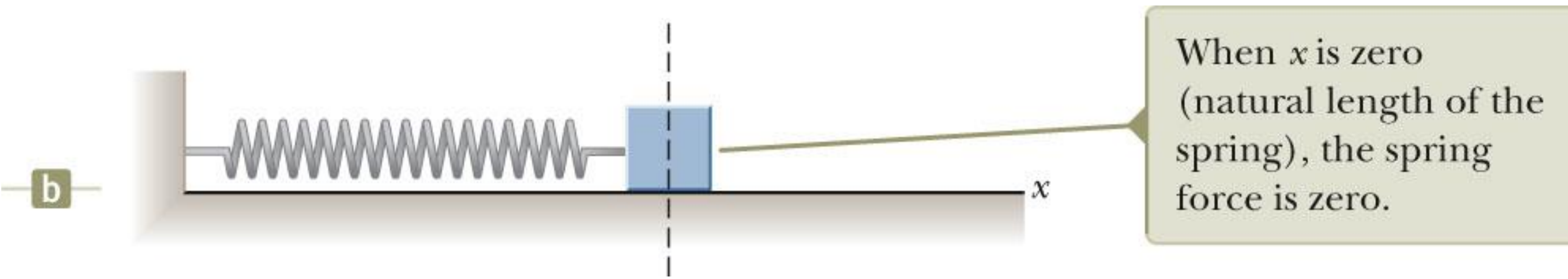
- Spring force

$$F_x = -kx$$

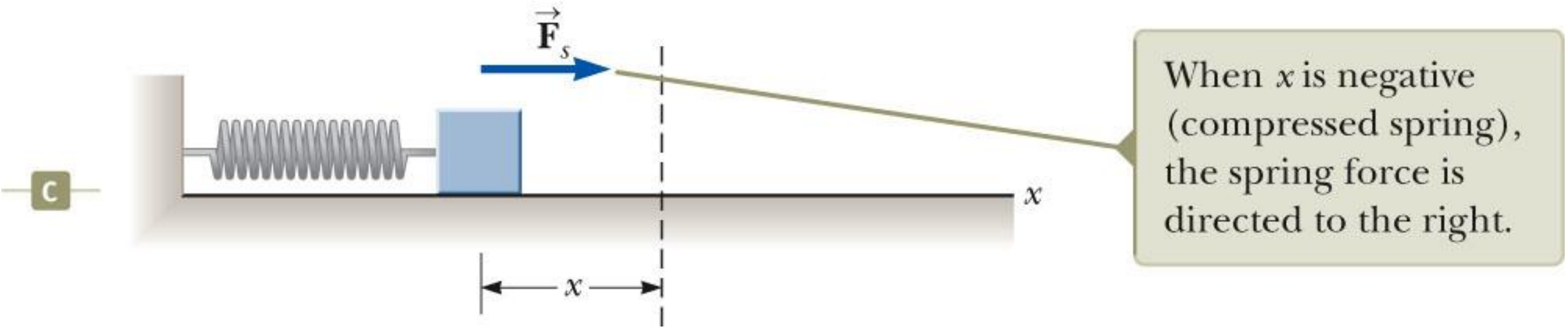


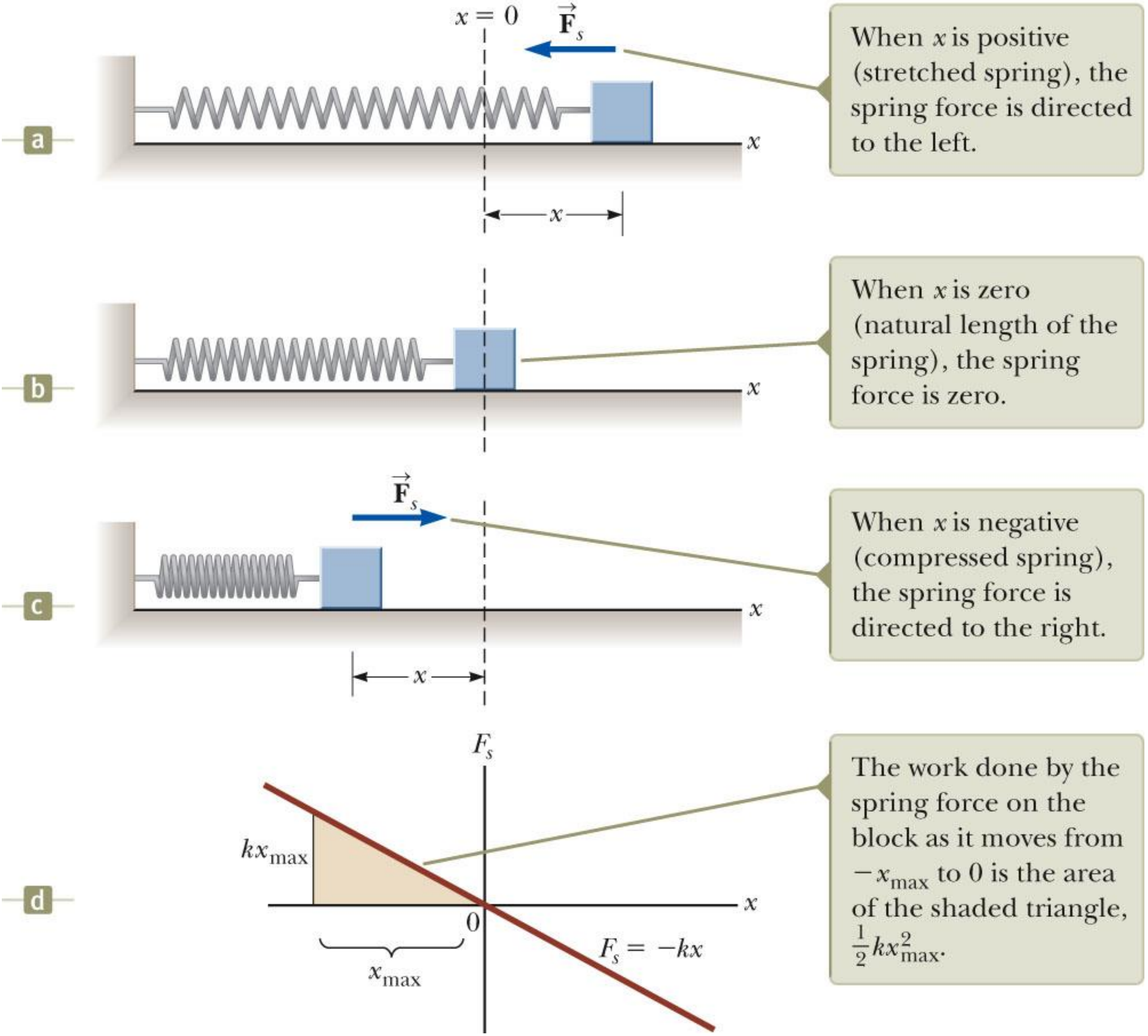
Spring at Equilibrium

- F = 0



Spring Compressed





$$\lim_{\Delta x \to 0} \sum_{x_i}^{x_f} F_x \Delta x = \int_{x_i}^{x_f} F_x dx$$

$$W = \int_{x_i}^{x_f} F_x dx = \int_{x_i}^{x_f} -kx\,dx$$

$$= \int_{-x_{max}}^{0} -kx\,dx = \tfrac{1}{2}kx^2$$

$$W = \int_{x_i}^{x_f} -kx\,dx = \tfrac{1}{2}kx_i^2 - \tfrac{1}{2}kx_f^2$$

Work done by spring on block

Fig. 7.9, p. 173

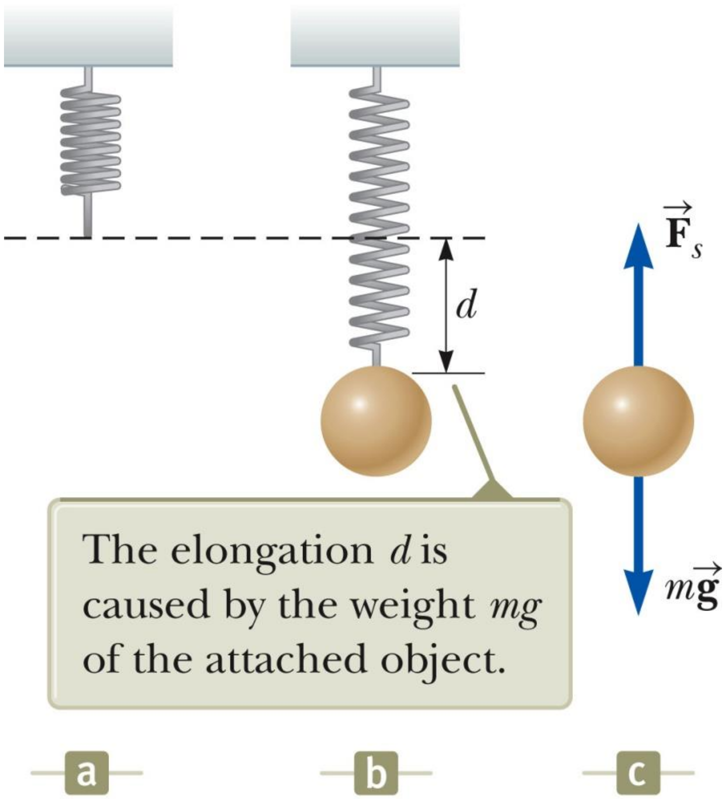
Measuring Spring Constant

- Start with spring at its natural equilibrium length.
- Hang a mass on spring and let it hang to distance d (stationary)
- From

$$F_x = kx - mg = 0$$

$$k = \frac{mg}{d}$$

so can get spring constant.



Find out the work done by spring force of spring constant 20in stretching the spring by 3 cm. m

Formula

Work done $= \frac{1}{2} kx^2$

$x = 3cm$

$= 3 \times 10^{-2} m$

$k = 20 \frac{N}{m}$

$W = \frac{1}{2} \times 20 \times (3 \times 10^{-2})^2$

$= 10 \times 9 \times 10^{-4}$

$= 90 \times 10^{-4}$ J

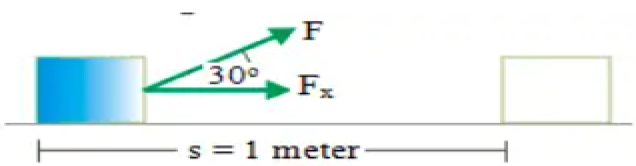
$= 0.9 \times 10^{-2}$ J

1. A person pulls a block 2 m along a horizontal surface by a constant force F = 20 N. Determine the work done by force F acting on the block.

Solution :

$$W = F\ d\ \cos\theta = (20)(2)(\cos 0) = (20)(2)(1) = 40\ \text{Joule}$$

2. A force F = 10 N acting on a box 1 m along a horizontal surface. The force acts at a 30^o angle as shown in figure below. Determine the work done by force F!



Known :

Force (F) = 10 N

The horizontal force (F_x) = $F \cos 30^o = (10)(0.5\sqrt{3}) = 5\sqrt{3}$ N

Displacement (d) = 1 meter

Wanted : Work (W) ?

Solution :

$W = F_x\ d = (5\sqrt{3})(1) = 5\sqrt{3}$ Joule

3. A body falls freely from rest, from a height of 2 m. If acceleration due to gravity is 10 m/s^2, determine the work done by the force of gravity!

Known :

Object's mass (m) = 1 kg

Height (h) = 2 m

Acceleration due to gravity (g) = 10 m/s^2

Wanted : Work done by the force of gravity (W)

Solution :

W = F d = w h = m g h

W = (1)(10)(2) = 20 Joule

W = work, F = force, d = distance, w = weight, h = height, m = mass, g = acceleration due to gravity.

4. An 1-kg object attached to a spring so it is elongated 2 cm. If acceleration due to gravity is 10 m/s^2, determine (a) the spring constant (b) work done by spring force on object

Known :

Mass (m) = 1 kg

Acceleration due to gravity (g) = 10 m/s^2

Elongation (x) = 2 cm = 0.02 m

Weight (w) = m g = (1 kg)(10 m/s^2) = 10 kg m/s^2 = 10 N

Wanted : Spring constant and work done by spring force

Solution :

(a) Spring constant

Formula of Hooke's law :

F = k x.

k = F / x = w / x = m g / x

k = (1)(10) / 0.02 = 10 / 0.02

$k = 500$ N/m

<u>(b) work done by spring force</u>

$W = -\frac{1}{2} k x^2$

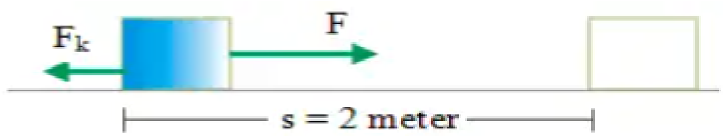
$W = -\frac{1}{2} (500)(0.02)^2$

$W = -(250)(0.0004)$

$W = -0.1$ Joule

The minus sign indicates that the direction of spring force is opposite with the direction of object displacement.

5. A force $F = 10$ N accelerates a box over a displacement 2 m. The floor is rough and exerts a friction force $F_k = 2$ N. Determine the net work done on the box.



Known :

Force (F) = 10 N

Force of kinetic friction (F_k) = 2 N

Displacement (d) = 2 m

Wanted : Net work (W_{net})

Solution :

Work done by force F :

$W_1 = F\ d \cos 0 = (10)(2)(1) = 20$ Joule

Work done by force of kinetic friction (F_k) :

$W_2 = F_k\ d = (2)(2)(\cos 180) = (2)(2)(-1) = -4$ Joule

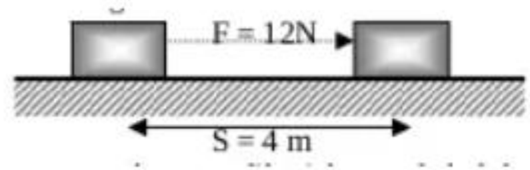
Net work :

$W_{net} = W_1 - W_2$

$W_{net} = 20 - 4$

$W_{net} = 16$ Joule

6. What is the work done by force F on the block.



Known :

Force (F) = 12 Newton

Displacement (d) = 4 meters

Wanted: Work (W)

Solution :

W = F d = (12 Newton)(4 meters) = 48 N m = 48 Joule

7. A block is pushed by a force of 200 N. The block's displacement is 2 meters. What is the work done on the block?

<u>Known :</u>

Force (F) = 200 Newton

Displacement (d) = 2 meters

<u>Wanted:</u> Work (W)

<u>Solution :</u>

Work :

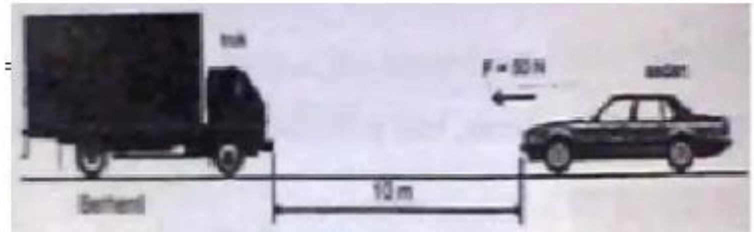
W = F s

W = (200 Newton)(2 meters)

W = 400 N m

W = 400 Joule

8. The driver of the sedan wants to park his car exactly 0.5 m in front of the truck which is at 10 m from the sedan's position. What is the work required by the sedan?



<u>Known :</u>

Displacement (d) = 10 meters – 0.5 meters
= 9.5 meters

Force (F) = 50 Newton

<u>Wanted :</u> Work (W)

<u>Solution :</u>

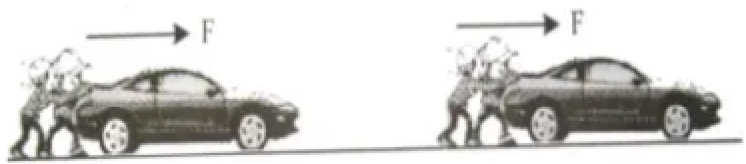
W = F s

W = (50 Newton)(9.5 meters)

W = 475 N m

W = 475 Joule

9.



Work done by Tom and Jerry so the car can move as far as 4 meters. Forces exerted by Tom and Jerry are 50 N and 70 N.

Known :

Displacement (s) = 4 meters

Net force (F) = 50 Newton + 70 Newton = 120 Newton

Wanted: Work (W)

Solution :

W = F s = (120 Newton)(4 meters) = 480 N m = 480 Joule

10. A driver pulling a car so the car moves as far as 1000 cm. What is the work done on the car?

Known :

Force (F) = 250 Newton

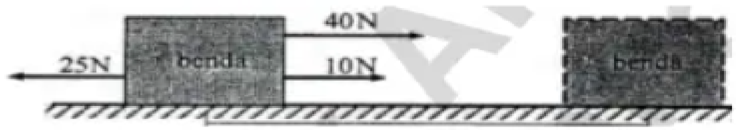
Displacement (s) = 1000 cm = 1000/100 meters = 10 meters

Wanted : Work (W)

Solution :

W = F s = (250 Newton)(10 meters) = 2500 N m = 2500 Joule

11. Based on figure below, if work done by net force is 375 Joule, determine object's displacement.



<u>Known :</u>

Work (W) = 375 Joule

Net force (ΣF) = 40 N + 10 N – 25 N = 25 Newton (rightward)

<u>Wanted :</u> Displacement (d)

<u>Solution :</u>

The equation of work :

W = F s

Object's displacement :

d = W / F = 375 Joule / 25 Newton