Lecture 12

(Ch5: 1-2)

Topic 5: Energy

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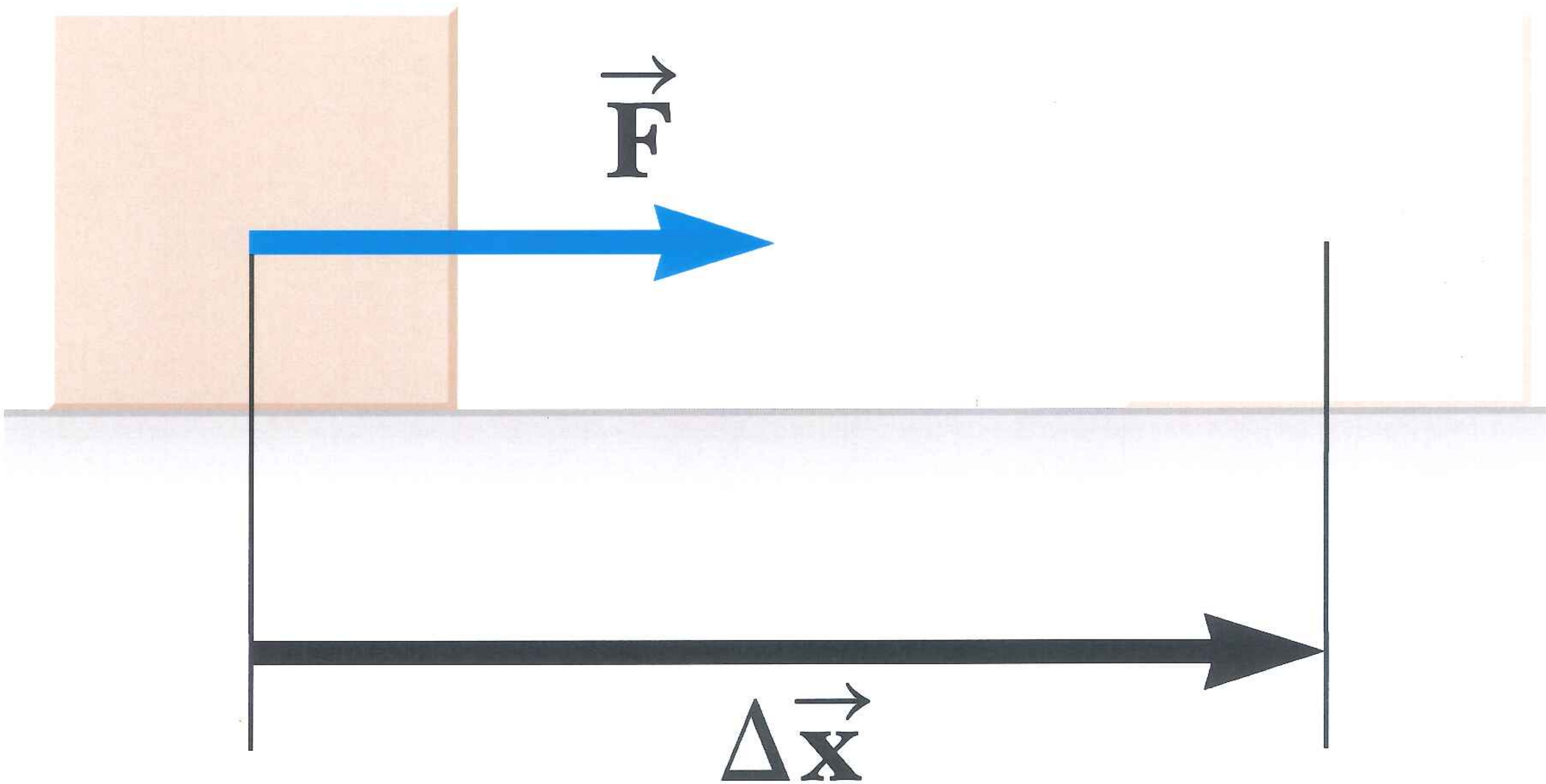
Chapter 5: Work and Energy

- Work
- Kinetic Energy
- Potential Energy
- Energy Conservation
- Springs
- Power
- Momentum, Impulse
- Conservation of Momentum

Work



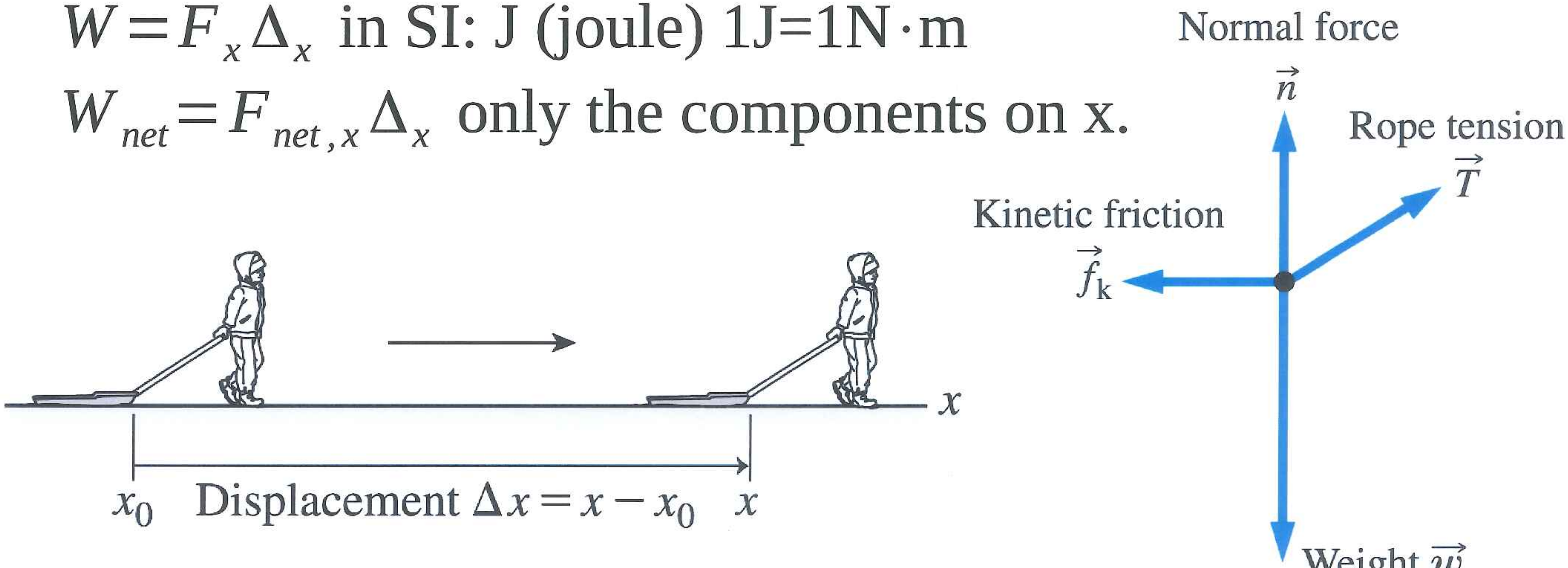
$W = F_x \Delta x$ SI unit: $\mathrm{J} = \mathrm{N} \cdot \mathrm{m} = \mathrm{kg} \cdot \mathrm{m}^2/\mathrm{s}^2$

Chapter 5: Work and Energy
Work done by a constant force

- Work done on an object is a quantity that relates the forces acting on the object and the displacement.
- Work and Net Work are **scalar** quantities.

$W = F_x \Delta_x$ in SI: J (joule) 1J=1N·m

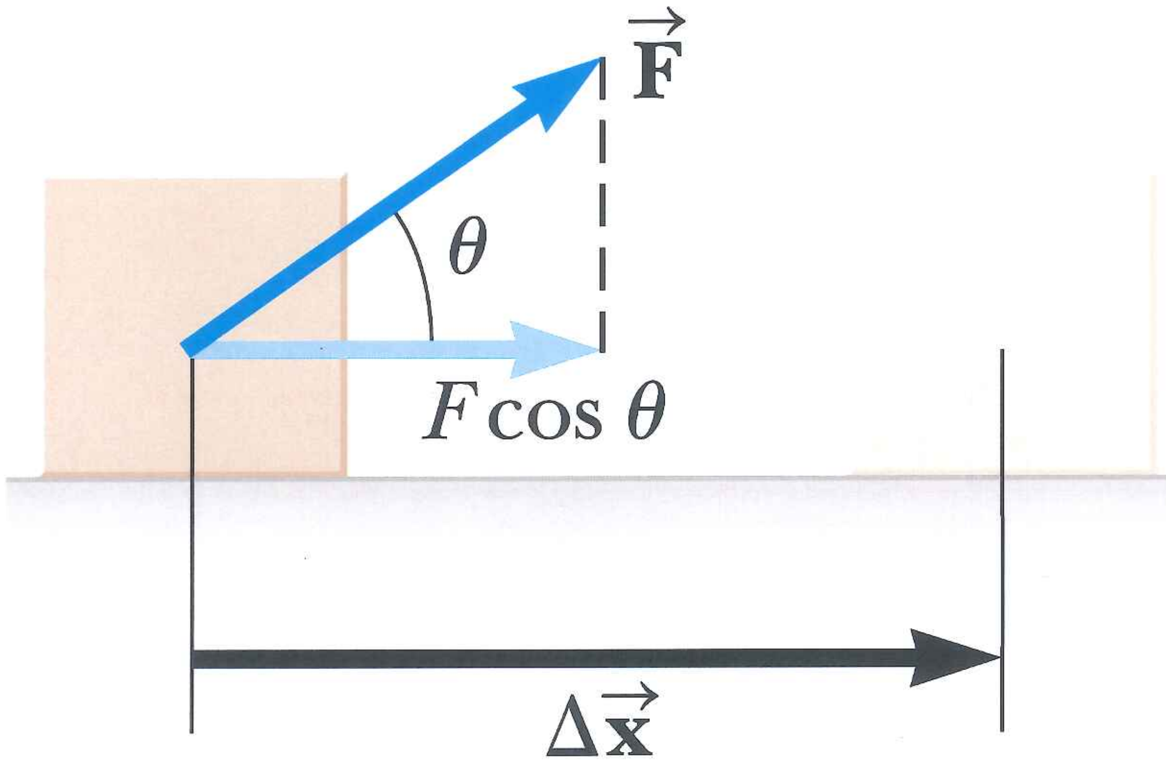
$W_{net} = F_{net,x} \Delta_x$ only the components on x.



(a) Displacement of sled

(b) Force diagram for sled

Work



$$F_x = F\cos\theta \quad \text{and} \quad F_y = F\sin\theta$$

$$W = \left(F\cos\theta\right)d$$

$$W = F_x \Delta x \quad \text{(Work done by a constant force in one-dimensional motion; SI unit: J)} \tag{5.1}$$

Loosely, work is *force times displacement*. More precisely, Equation 5.1 shows that work involves only the component of force in the direction of displacement. Work is a *scalar* quantity. Multiplying SI units of force (N) and displacement (m) gives the units for work: N · m. This combination defines a new SI unit, the **joule** (J), with

$$1\ \text{J} = 1\ \text{N} \cdot \text{m}$$

Chapter 5: Work and Energy
Work done by a constant force

- Work and angles relative to the displacement

$$F_x = F\cos\theta$$

$$W = F_x \Delta_x = F\cos\theta\,\Delta_x$$

- θ < 90° means that cosθ is positive and the work is positive.
- θ > 90° means that cosθ is negative and the work is negative.
- θ = 90° means that cosθ is 0 and the work is positive; the force has no component on the displacement axis and the work is 0 (normal force).

$$W_{net} = W_1 + W_2 + \cdots + W_n \quad \text{(Net work done by multiple forces; SI unit: J)} \quad (5.2)$$

Each individual value of work (W_1, W_2, etc.) is defined by Equation 5.1, which leads to another expression for net work:

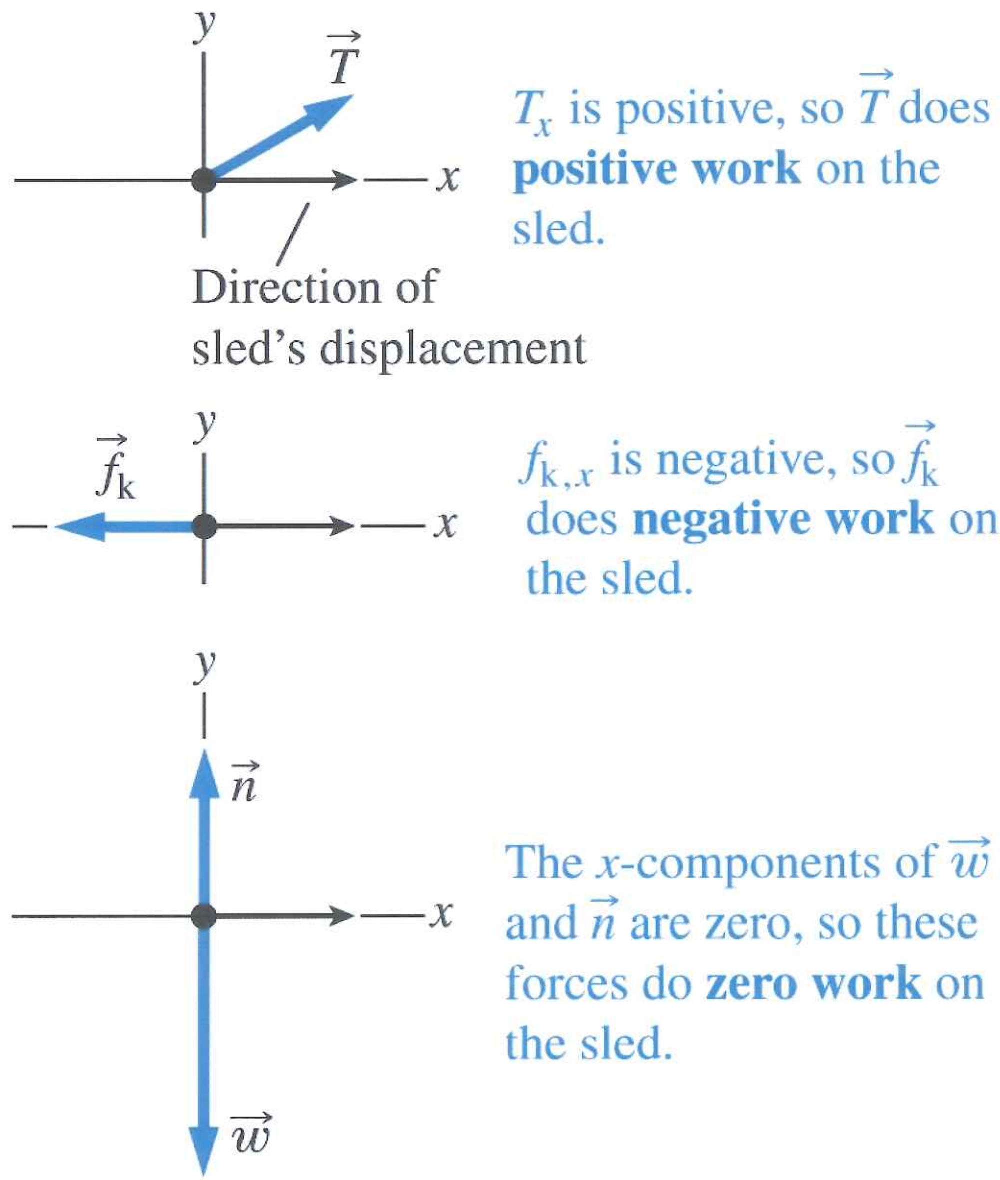
$$\begin{aligned} W_{net} &= F_{1x}\Delta x + F_{2x}\Delta x + \cdots + F_{nx}\Delta x \\ &= (F_{1x} + F_{2x} + \cdots + F_{nx})\Delta x \end{aligned}$$

The quantity in parentheses is just the x-component of the net force acting on the object, so

$$W_{net} = F_{net,x}\Delta x \quad \text{(Net work done by multiple forces; SI unit: J)} \quad (5.3)$$

Figure 5.2

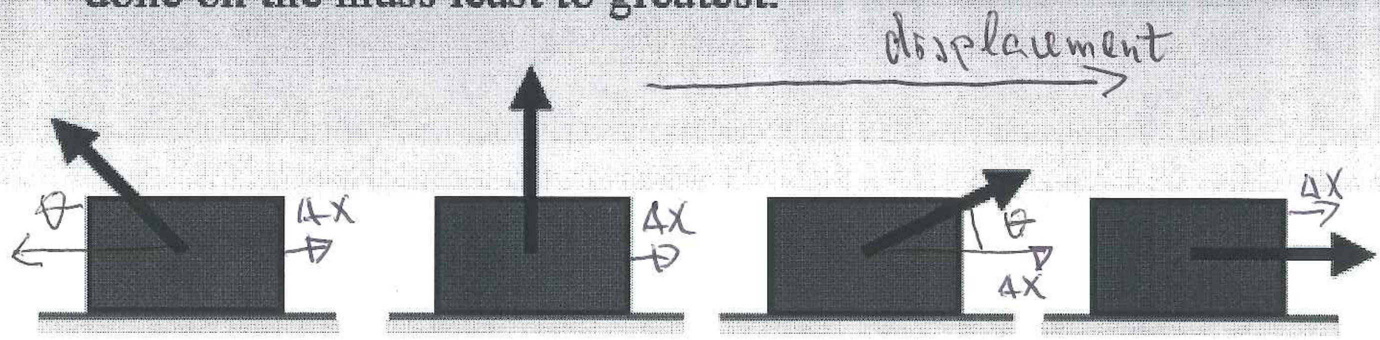
Because $W = F_x \Delta x$, the sign of work depends on the signs of Δx and F_x:



in general work $W = (F\cos\theta) \cdot \Delta x$

Work

The diagrams below show four situations in which a constant force acts on a mass *m*. The magnitudes of the forces are equal, and the mass slides to the right a distance *d*. Rank the diagrams according to the work done on the mass least to greatest.



(a) (b) (c) (d)

or $W = F_x \cdot \Delta X$

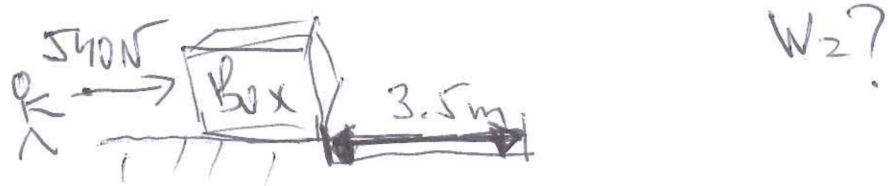
$= F\cos\theta \cdot \Delta X$

$W = F \cdot d \cdot \cos\theta$ (−)

$W = 0$

$W = F \cdot d \cdot \cos\theta$

$W = F \cdot d$



29. ORGANIZE AND PLAN The force you apply on the box is in the same direction as the displacement, so F_x and Δx must have the same sign. Let's define this direction to be our positive x-direction.

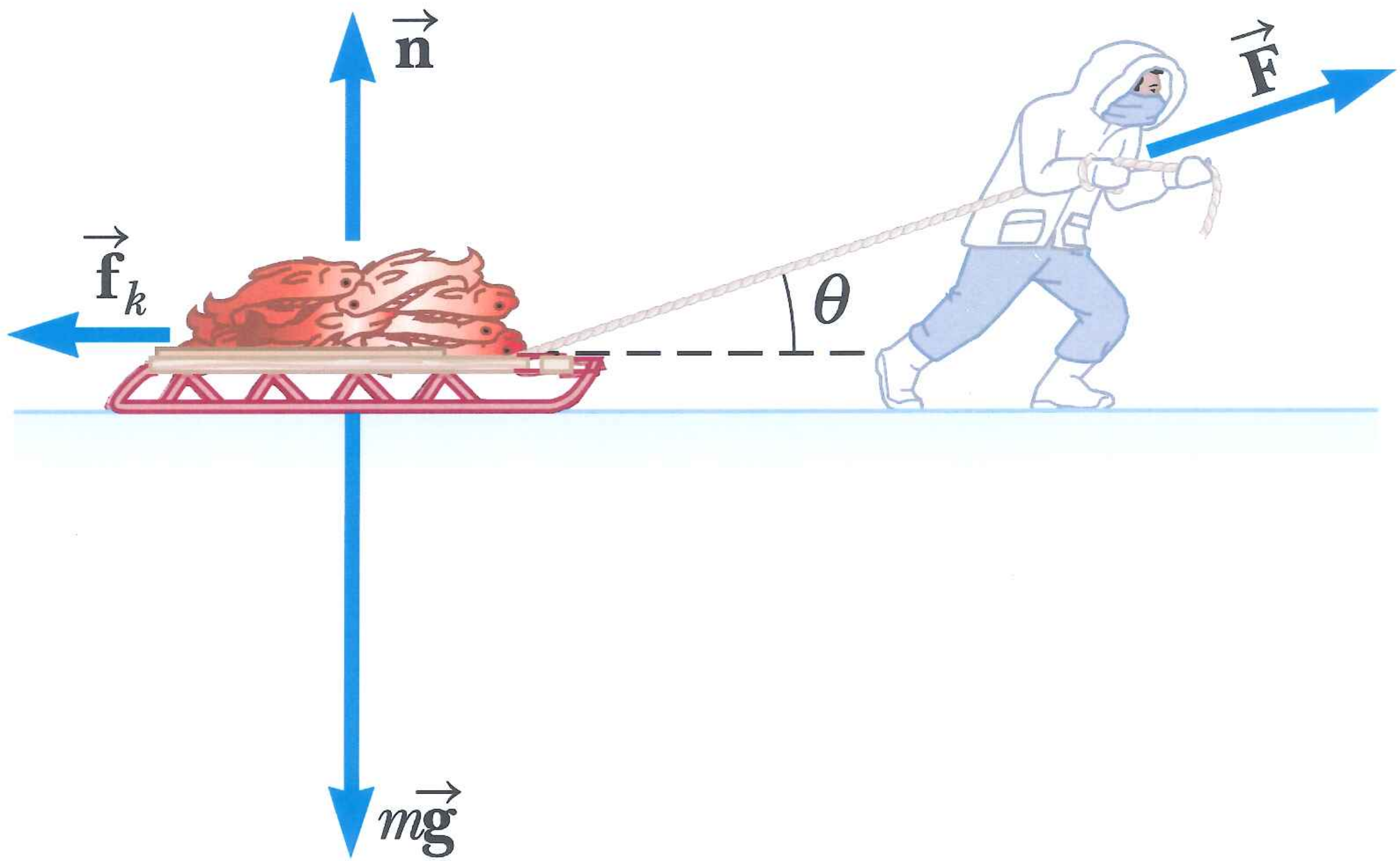
Known: $F_x = 540$ N; $\Delta x = 3.5$ m.

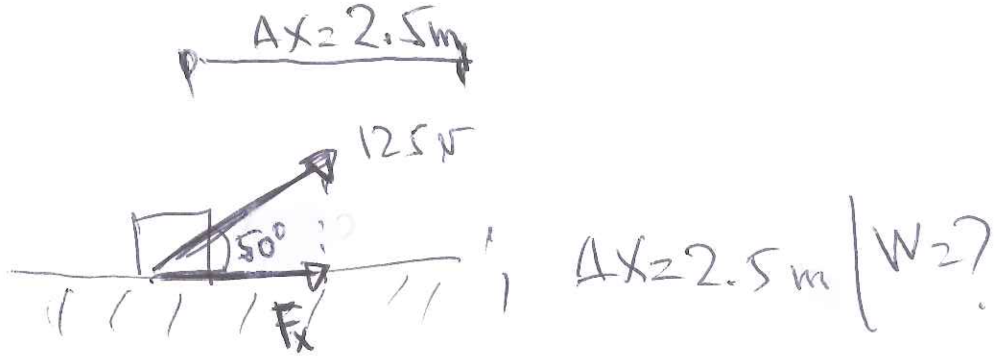
SOLVE We compute the work you do by using Equation 5.1:

$$W = F_x \Delta x = (540\text{ N})(3.5\text{ m}) = 1.89\text{ kJ} = 1890\text{ J}$$

REFLECT You do positive work, against the negative work done by friction.

Conservative and Nonconservative Forces





30. ORGANIZE AND PLAN This is work done by a constant force in one-dimensional motion, so Equation 5.4 will apply.

Known: $F = 125$ N; $\theta = 50°$; $\Delta x = 2.5$ m.

SOLVE We compute the work done on the object by the force F from Equation 5.4:

$$W = (F\cos\theta)\Delta x = (125\text{ N})(\cos 50°)(2.5\text{ m}) = 201\text{ J}$$

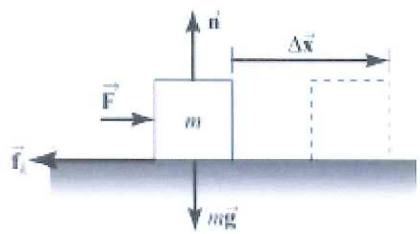
REFLECT There must also be at least one other force acting on the object, otherwise the force F would accelerate the object in the $+y$-direction.

6. A horizontal force of 150 N is used to push a 40.0-kg packing crate a distance of 6.00 m on a rough horizontal surface. If the crate moves at constant speed, find

   a. the work done by the 150-N force and

   b. the coefficient of kinetic friction between the crate and surface.

5.6 (a) $W_F = F(\Delta x)\cos\theta = (150\text{ N})(6.00\text{ m})\cos 0° = \boxed{900\text{ J}}$



(b) Since the crate moves at constant velocity, $a_x = a_y = 0$. Thus,

$$\Sigma F_x = 0 \Rightarrow f_k = F = 150\text{ N}$$

Also,

$$\Sigma F_y = 0 \Rightarrow n = mg = (40.0\text{ kg})(9.80\text{ m/s}^2) = 392\text{ N}$$

so

$$\mu_k = \frac{f_k}{n} = \frac{150\text{ N}}{392\text{ N}} = \boxed{0.383}$$

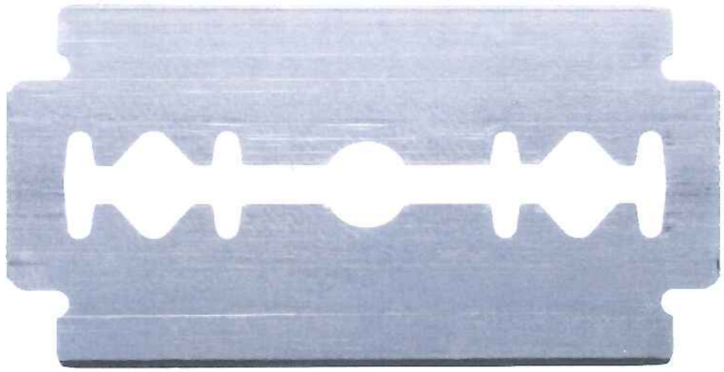
10. A 2-kg object is moving at 3 m/s. A 4-N force is applied in the direction of motion and then removed after the object has traveled an additional 5 m. The work done by this force is:

1) 12 J
2) 15 J
3) 18 J
4) 20 J

$W = F \cdot d = (4\,N) \cdot (5\,m)$

$= 20\,J$

Work and Dissipative Forces



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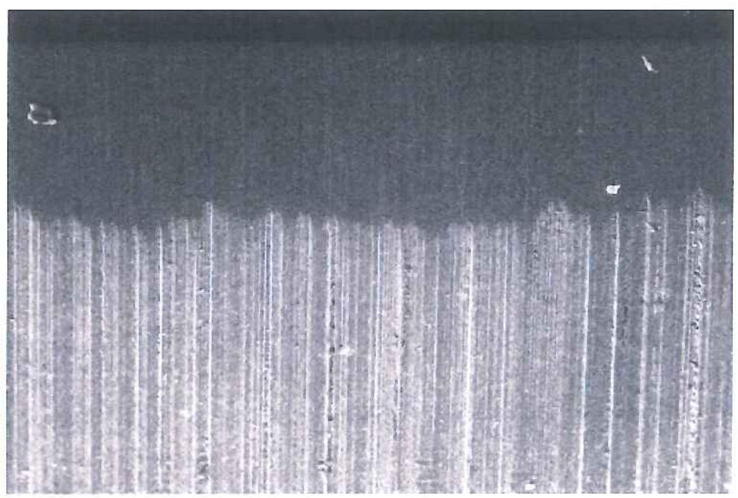

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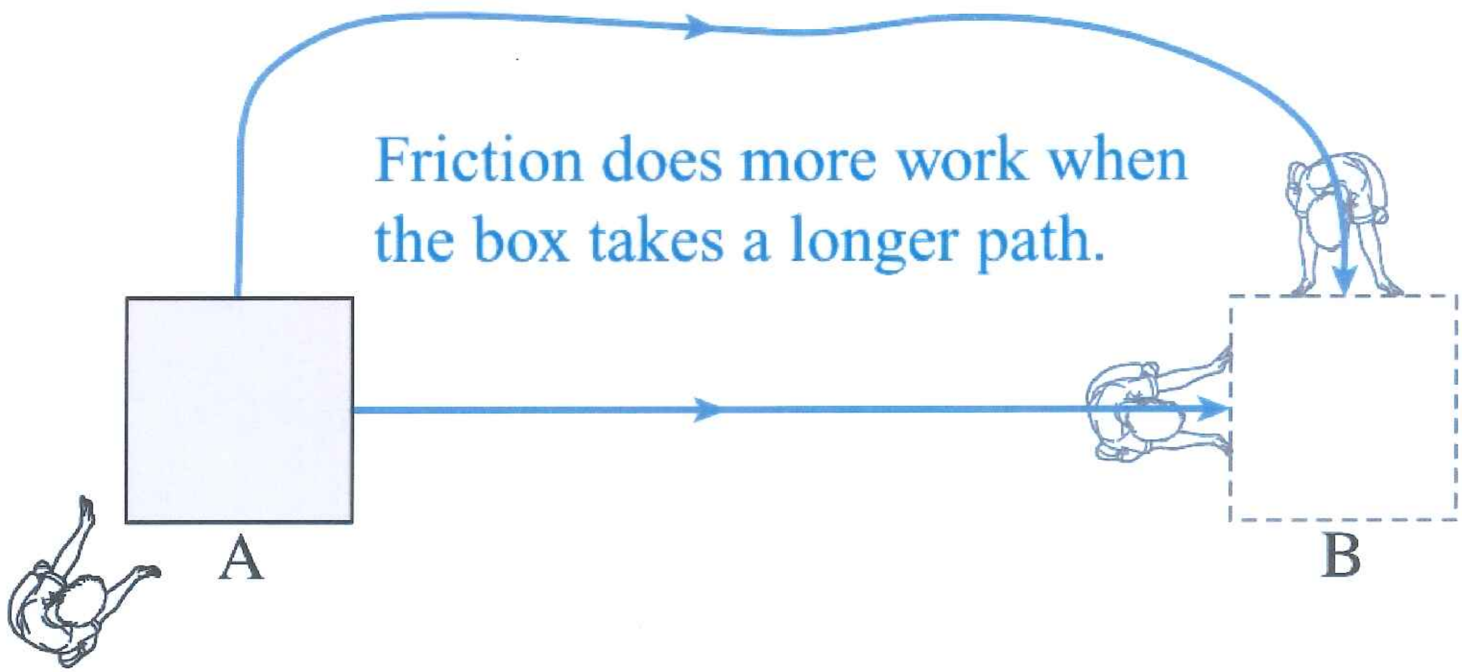
Chapter 5: Work and Energy
Potential Energy

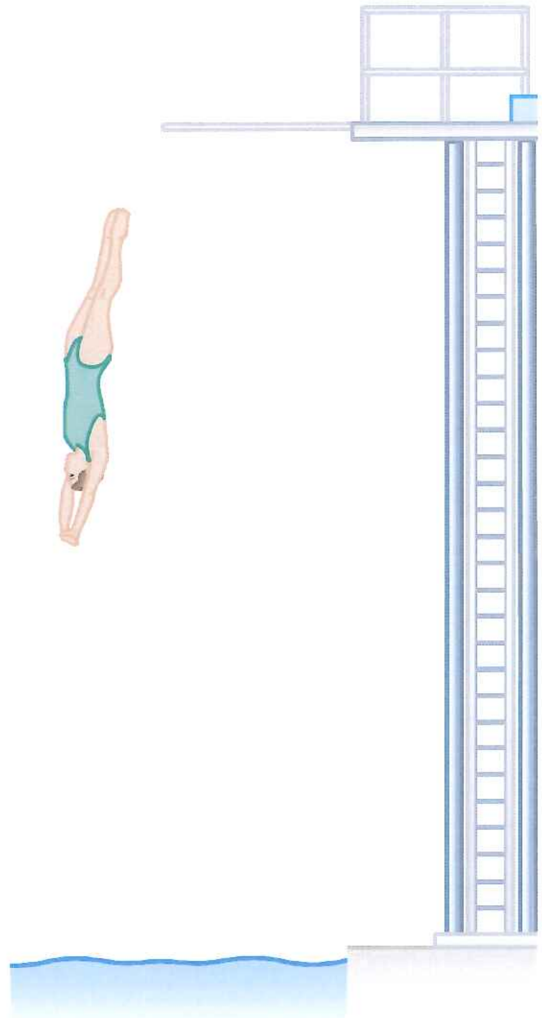
Nonconservative forces:

If the work done by a force on an object moving between two point depends on the path taken, then that force is **nonconservative**.

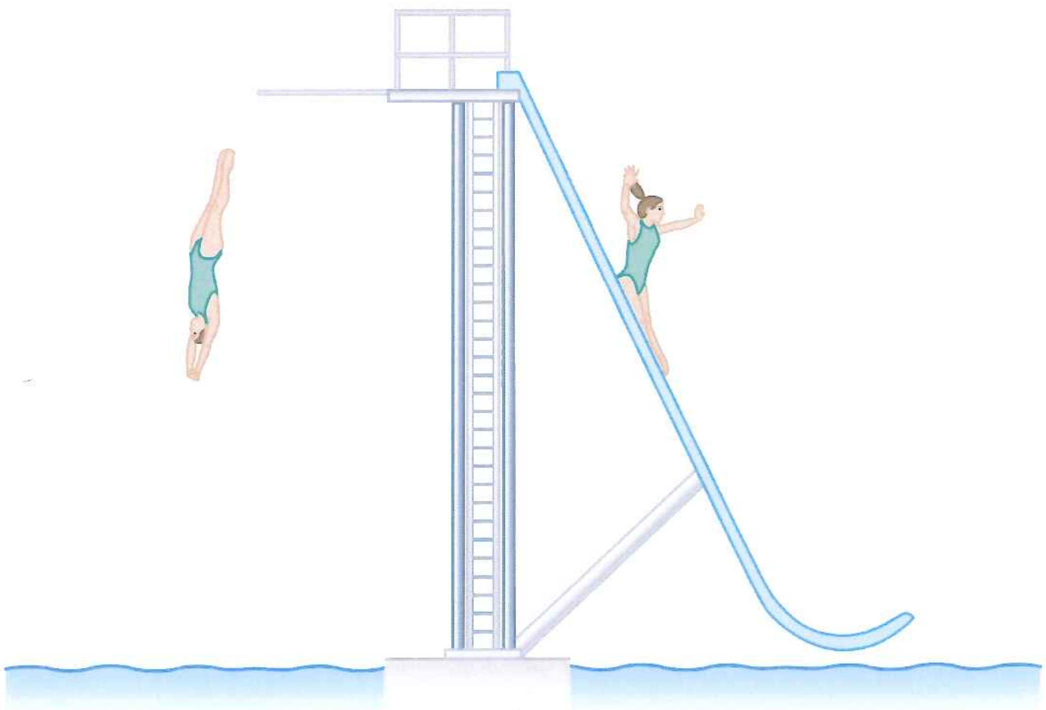
The work done by friction $\boldsymbol{f_k}$ depends on the path.

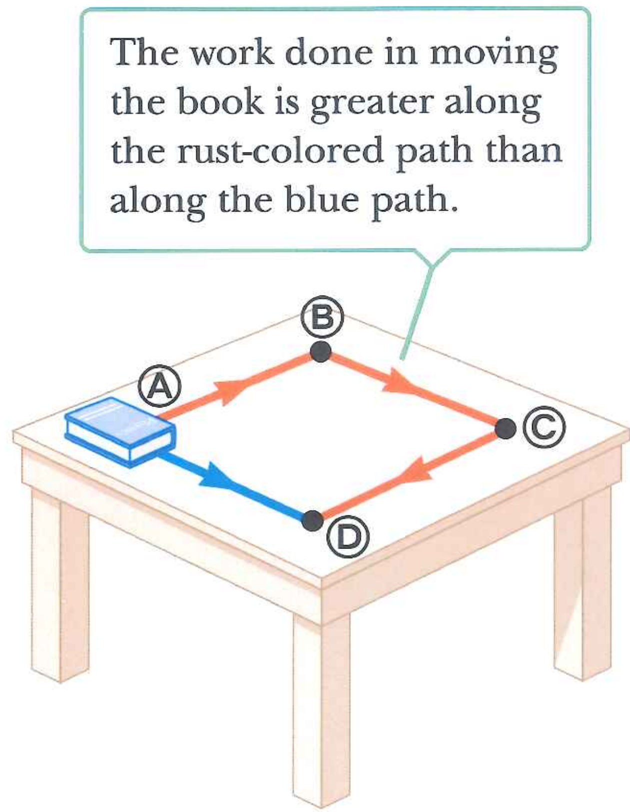


Conservative and Nonconservative Forces



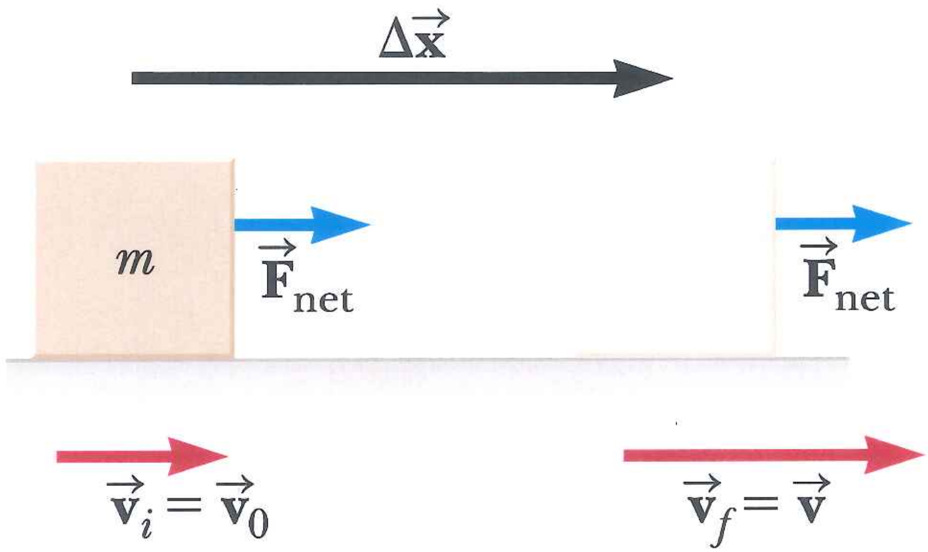
Conservative and Nonconservative Forces





Conservative force → work force does moving an object between two points is path-independent

Kinetic Energy and the Work–Energy Theorem



$$W_{net} = F_{net}\Delta x = (ma)\Delta x$$

$$v^2 = v_0^{\,2} + 2a\Delta x \rightarrow a\Delta x = \frac{v^2 - v_0^{\,2}}{2}$$

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

Chapter 5: Work and Energy
Changing speed and Kinetic energy

$$v_x^2 = 2x \cdot a_x + v_{x0}^2 \rightarrow ax = \frac{v_x^2 - v_{x0}^2}{2}$$

$$W = F_x \Delta_x = ma\Delta_x \longrightarrow W = \frac{m}{2}\left(v_x^2 - v_{x0}^2\right)$$

$$W = \frac{mv^2}{2} - \frac{mv_0^2}{2}$$

$K = \dfrac{mv^2}{2}$ Kinetic energy; in SI units: J

$W_{net} = K - K_0 = \Delta K$ The total work is the change in kinetic energy.

Kinetic Energy and the Work–Energy Theorem

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

Kinetic Energy: $KE = \frac{1}{2}mv^2$ SI unit: $\text{J} = \text{kg}\cdot\text{m}^2/\text{s}^2$

Work-Energy Theorem: $W_{\text{net}} = KE_f - KE_i = \Delta KE$

Conservative and Nonconservative Forces

Work-Energy Theorem: $W_{nc} + W_c = \Delta KE$

Chapter 5: Work and Energy
Changing speed and Kinetic energy

Question 5.8 Kinetic Energy I

By what factor does the kinetic energy of a car change when its speed is tripled?

a) no change at all
b) factor of 3
c) factor of 6
d) factor of 9
e) factor of 12

Chapter 5: Work and Energy
Changing speed and Kinetic energy

Question 5.9 Kinetic Energy II

Car #1 has twice the mass of car #2, but they both have the same kinetic energy. How do their speeds compare?

a) $2v_1 = v_2$

b) $\sqrt{2}v_1 = v_2$

c) $4v_1 = v_2$

d) $v_1 = v_2$

e) $8v_1 = v_2$

10. A 7.00-kg bowling ball moves at 3.00 m/s. How fast must a 2.45-g Ping-Pong ball move so that the two balls have the same kinetic energy?

5.10 Requiring that $KE_{\text{ping pong}} = KE_{\text{bowling}}$, with $KE = \frac{1}{2}mv^2$, we have

$$\frac{1}{2}\left(2.45\times10^{-3}\text{ kg}\right)v^2 = \frac{1}{2}(7.00\text{ g})(3.00\text{ m/s})^2$$

giving $v = \boxed{160\text{ m/s}}$

14. BIO A 62.0-kg cheetah accelerates from rest to its top speed of 32.0 m/s.

a. How much net work is required for the cheetah to reach its top speed?

b. One food Calorie equals 4 186 J. How many Calories of net work are required for the cheetah to reach its top speed? *Note:* Due to inefficiencies in converting chemical energy to mechanical energy, the amount calculated here is only a fraction of the power that must be produced by the cheetah's body.

5.14 **(a)** From the work-energy theorem, the required net work equals the change in the cheetah's kinetic energy. The cheetah starts from rest, so its initial kinetic energy, KE_i, equals zero and

$$\begin{aligned} W_{net} &= \Delta KE = KE_f - KE_i \\ &= KE_f \\ &= \tfrac{1}{2}mv^2 = \tfrac{1}{2}(62.0\ \text{kg})(32.0\ \text{m/s})^2 \\ &= \boxed{3.17\times10^4\ \text{J}} \end{aligned}$$

(b) Converting to Calories gives:

$$W_{net} = 3.17\times10^4\ \text{J}\left(\frac{1\ \text{Calorie}}{4\ 186\ \text{J}}\right) = \boxed{7.57\ \text{Calories}}$$

4. A shopper in a supermarket pushes a cart with a force of 35 N directed at an angle of 25° below the horizontal. The force is just sufficient to overcome various frictional forces, so the cart moves at constant speed.

a. Find the work done by the shopper as she moves down a 50.0-m length aisle.

b. What is the *net work* done on the cart? Why?

c. The shopper goes down the next aisle, pushing horizontally and maintaining the same speed as before. If the work done by frictional forces doesn't change, would the shopper's applied force be larger, smaller, or the same? What about the work done on the cart by the shopper?

5.4 **(a)** The 35 N force applied by the shopper makes a 25° angle with the displacement of the cart (horizontal). The work done on the cart by the shopper is then

$$W_{shopper} = (F\cos\theta)\Delta x = (35\text{ N})(\cos 25°)(50.0\text{ m}) = \boxed{1.6\times10^3\text{ J}}$$

(b) Since the speed of the cart is constant, $KE_f = KE_i$ and $W_{net} = \Delta KE = \boxed{0}$.

(c) Since the cart continues to move at constant speed, the net work done on the cart in the second aisle is again zero. With both the net work and the work done by friction unchanged, the work done by the shopper ($W_{shopper} = W_{net} - W_{friction}$) is also $\boxed{\text{unchanged}}$. However, the shopper now pushes horizontally on the cart, making

$\boxed{F' = W_{shopper}/(\Delta x\cdot\cos 0°) = W_{shopper}/\Delta x \text{ smaller than before}}$ when the force was $F = W_{shopper}/(\Delta x\cdot\cos 35°)$.

16. A 0.60-kg particle has a speed of 2.0 m/s at point *A* and a kinetic energy of 7.5 J at point *B*. What is

a. its kinetic energy at *A*?

b. Its speed at point *B*?

c. The total work done on the particle as it moves from *A* to *B*?

5.16 **(a)** $KE_A = \frac{1}{2}mv_A^2 = \frac{1}{2}(0.60\text{ kg})(2.0\text{ m/s})^2 = \boxed{1.2\text{ J}}$

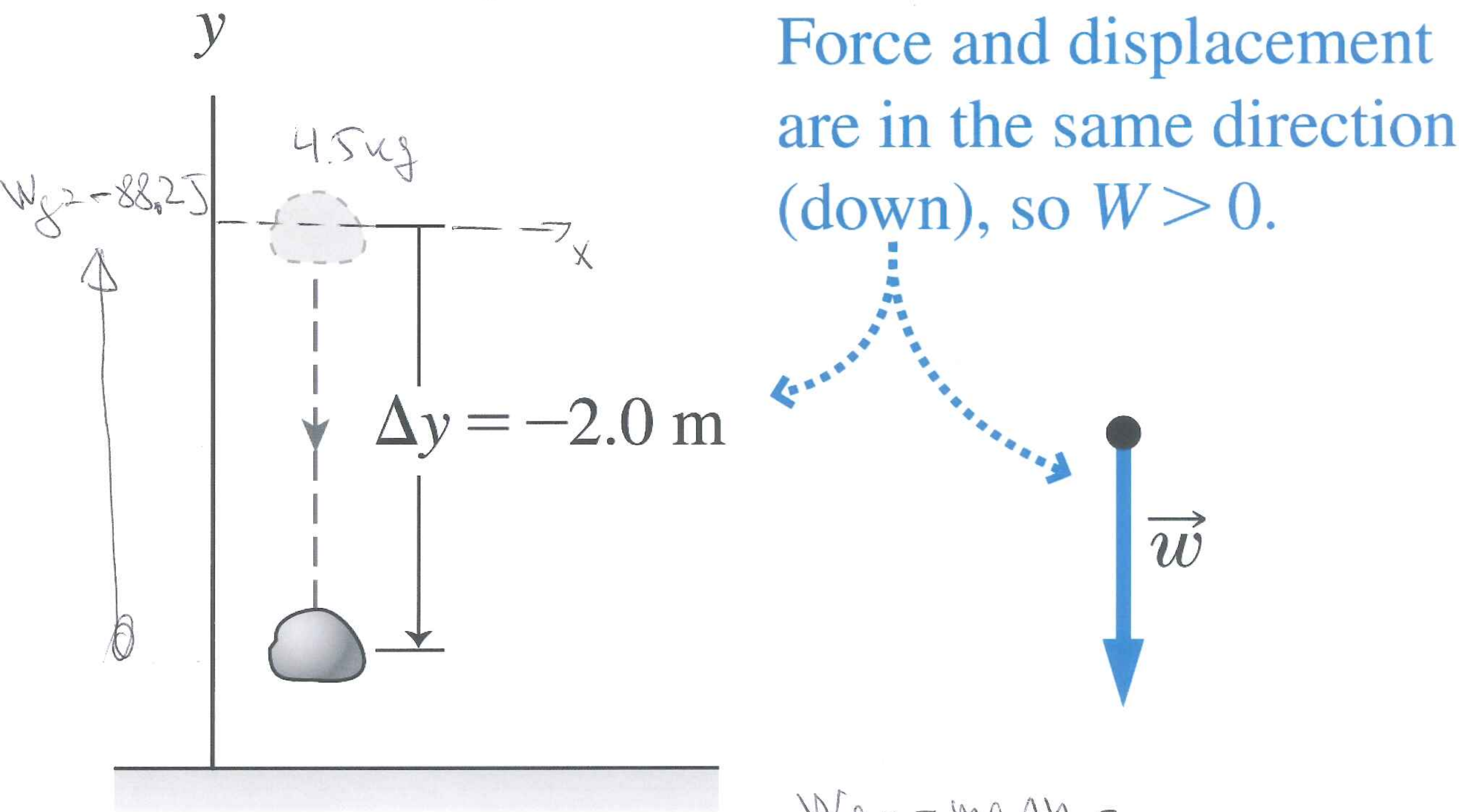
(b) $KE_B = \frac{1}{2}mv_B^2$, so

$$v_B = \sqrt{\frac{2(KE_B)}{m}} = \sqrt{\frac{2(7.5\text{ J})}{0.60\text{ kg}}} = \boxed{5.0\text{ m/s}}$$

(c) $W_{net} = \Delta KE = KE_B - KE_A = (7.5 - 1.2)\text{ J} = \boxed{6.3\text{ J}}$

Figure 5.6

Work done by Gravity



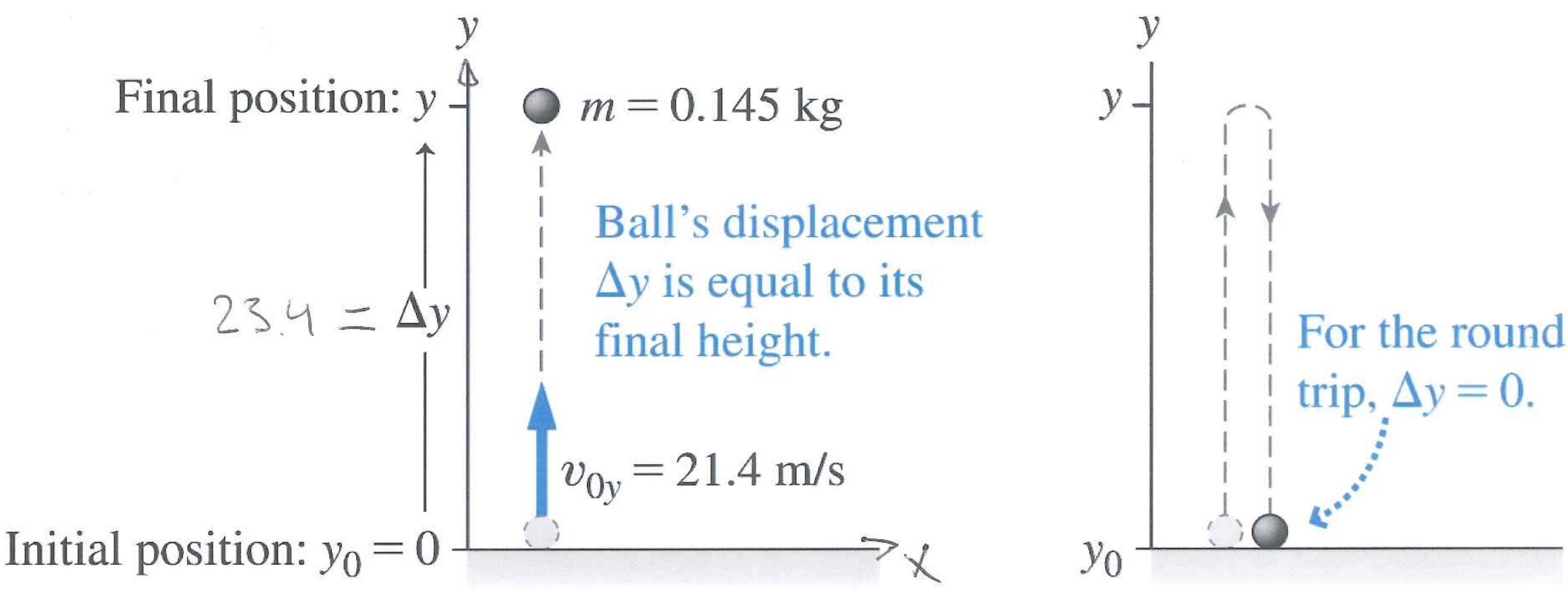
$W_g = -mg\Delta y =$

$-(4.5\text{kg})(9.82\frac{\text{m}}{\text{s}^2})(-2\text{m}) =$

$= 88.2$ J

Figure 5.7

Work done by Gravity



(a) Ball's upward flight

(b) The round trip

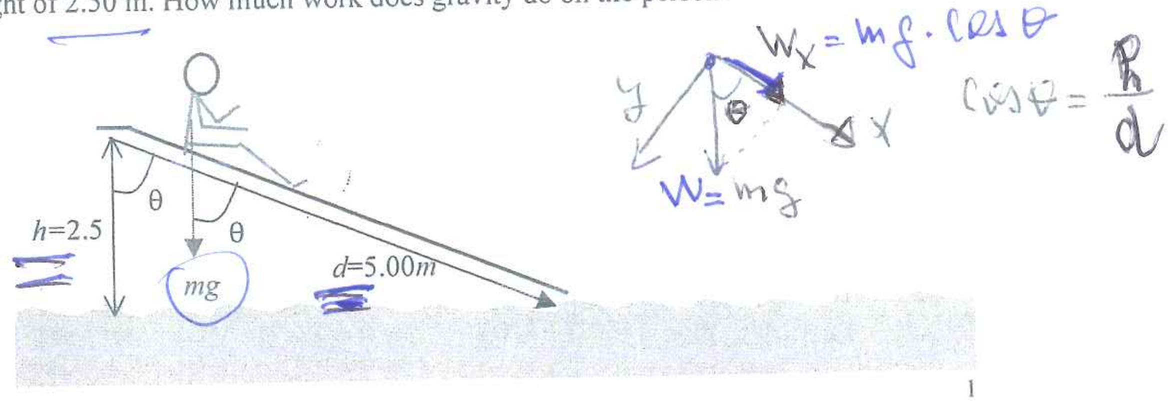
$y_{max} = ?$; $W_g = ?$ upward ; $W_g = ?$ entire trip

$W = (-mg)\Delta y = -(0.145 \times 9.82) \times 23.4 =$

$= -33.3$ J

Example

A 75.0-kg person slides a distance of 5.00m on a straight water slide, dropping through a vertical height of 2.50 m. How much work does gravity do on the person?



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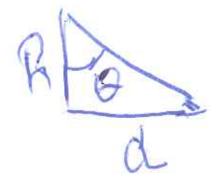
Answer:



The gravity along the displacement has a magnitude $mg\cos\theta$.

By the definition of work done, the work done of the gravity on the person is given by

$$W = (mg\cos\theta)\,d = mg\,(h/d)\,d = mgh = (75.0)(9.8)(2.50) = 1837.5\ \text{J}$$

$F_x = W_x$