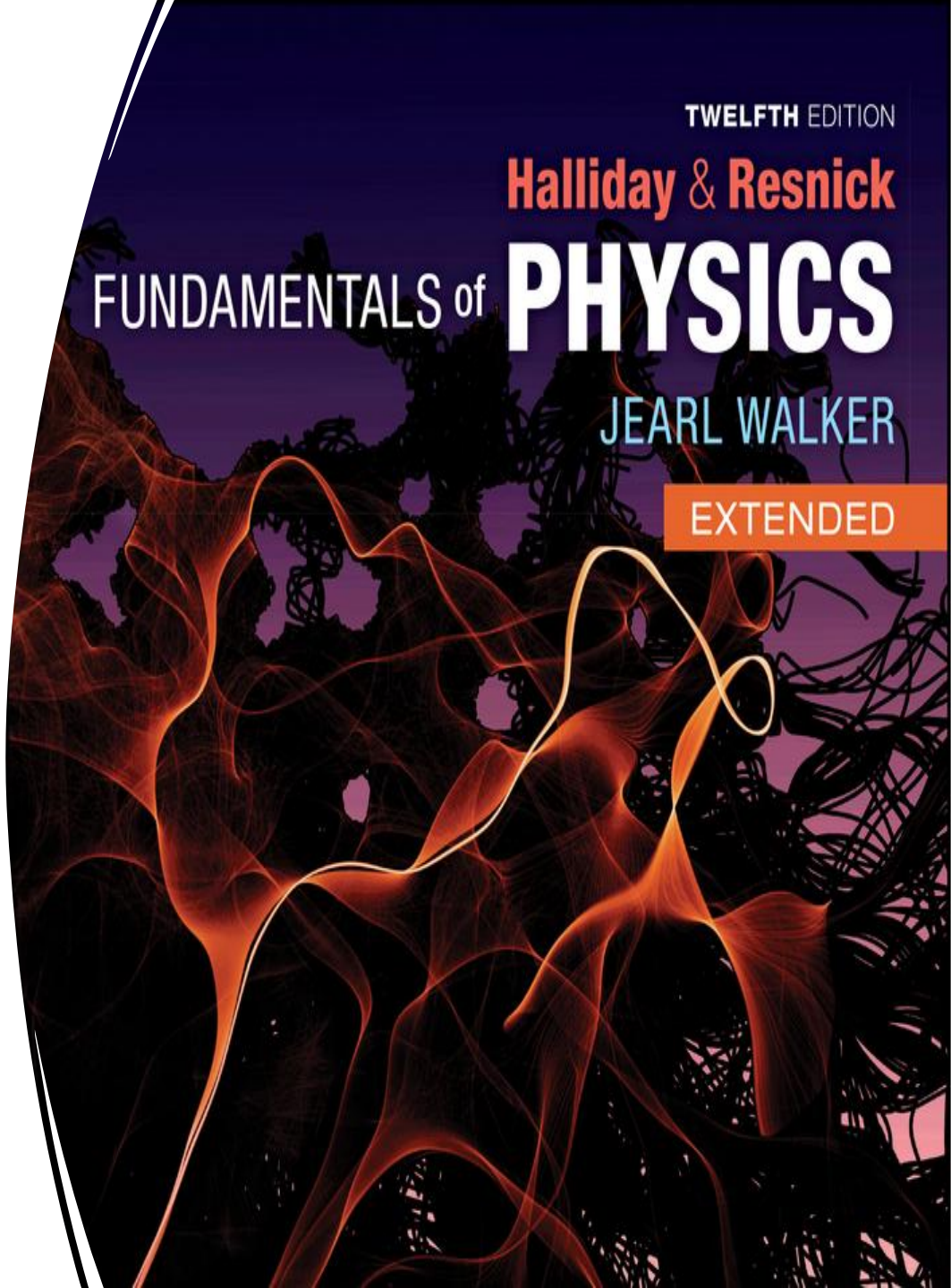
# Chapter 7

# Kinetic Energy and Work



# Units of Chapter 7


7.1. Kinetic Energy

7.2. Work and Kinetic Energy

7.3. Work done by the Gravitational Force

7.4. Work done by a Spring

7.5. Work done by a general variable force

7.6. Power

# Energy

In **physics**, **energy** is a property of objects which can be transferred or transformed to other objects or converted into different forms, but cannot be created or destroyed.

Energy is required for any sort of motion

**Energy** is the ability to supply or create work

# 7.1 Kinetic Energy

**Kinetic energy (*K*)** is energy associated with the *state of motion* of an object.

- The faster an object moves, the greater its kinetic energy
- Kinetic energy is zero for a stationary object

- For an object with $v$ well below the speed of light:

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

- The unit of kinetic energy is a **joule** (J)

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

**Example 1.** In 1896 in Waco, Texas, William Crush parked two locomotives at opposite ends of a 6.4-km-long track, fired them up, tied their throttles open, and then allowed them to crash head-on at full speed. Assuming each locomotive weighed $1.2 \times 10^6$ N and its acceleration was a constant 0.26 m/s$^2$, what was the total kinetic energy of the two locomotives just before the collision?

Answer: $K = 2.0 \times 10^8\ J$

**Solution**

What energy is released by two colliding trains with given weight and acceleration from rest:

Find the final velocity of each locomotive:

$$\begin{aligned} v^2 &= v_0^2 + 2a(x - x_0). \\ v^2 &= 0 + 2(0.26\,\text{m/s}^2)(3.2\times10^3\,\text{m}), \\ v &= 40.8\,\text{m/s} \end{aligned}$$

Convert weight to mass: $m = \dfrac{1.2\times10^6\,\text{N}}{9.8\,\text{m/s}^2} = 1.22\times10^5\,\text{kg}.$

Find the kinetic energy using mass and velocity:

$$\begin{aligned} K &= 2\left(\frac{1}{2}mv^2\right) = (1.22\times10^5\,\text{kg})(40.8\,\text{m/s})^2 \\ &= 2.0\times10^8\,\text{J}. \quad (\text{Answer}) \end{aligned}$$

**Example 2.** A truck moving at 15 m/s has kinetic energy of $4.2 \times 10^5$J.

(a) What is the mass of the truck?

(b) By what multiplicative factor does the kinetic energy increase if its speed is doubled?

Answers: a) m= 3733 Kg , b) KE increases by four

$$m = \frac{2K}{v^2} = 3733\ kg$$

$$K' = \frac{1}{2}m(2v)^2 = \frac{1}{2}m4(v)^2 = 4\left(\frac{1}{2}mv^2\right) = 4K$$

**(b)** Kinetic energy depends on the speed squared, and hence doubling the speed increases the kinetic energy by a factor of four.

# 7.2 Work and Kinetic Energy

## Work Done by a Constant Force

In physics, a force is said to do **work** if, when acting on a body, there is a displacement of the point of application in the direction of the force.

**Work** is the ability to supply force and a change in distance to an object

The concept of ***work*** provides a link between force and energy.

# 7.2 Work and Kinetic Energy

## Work Done by a Constant Force

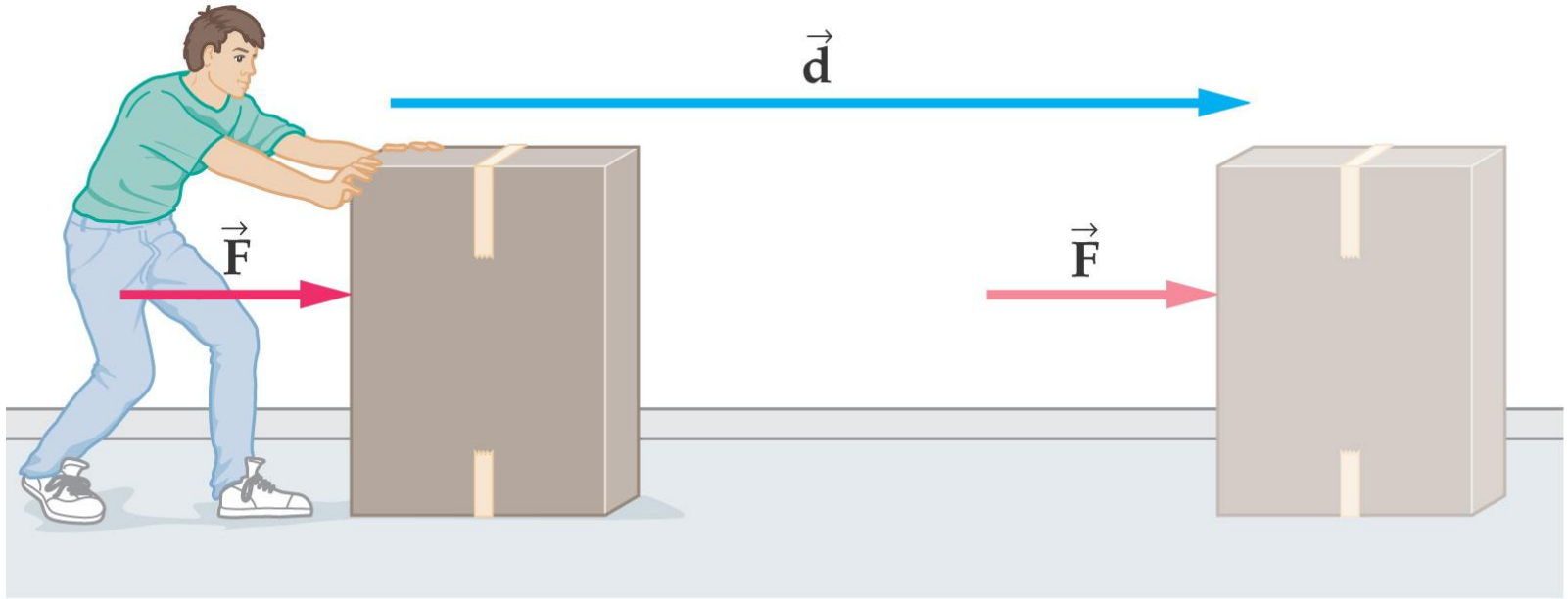
### Force in the Direction of Displacement

The definition of work, when the force is parallel to the displacement:

$$W = Fd$$

SI unit: newton-meter $(\mathrm{N \cdot m})$ = joule, J

**Work is a scalar quantity**



# 7.2 Work and Kinetic Energy

## Force at an Angle to the Displacement

The work done by a constant force *F* is defined as:

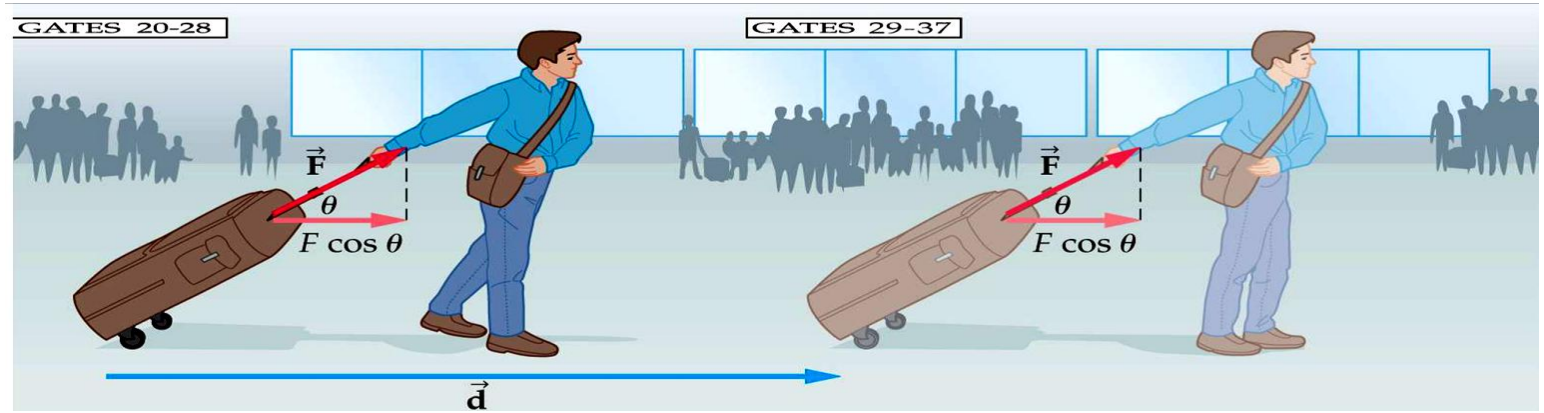
$$W = Fd\cos\theta$$

*F* is the applied force, *d* is the displacement of the object, θ is the angle between the force and the displacement.

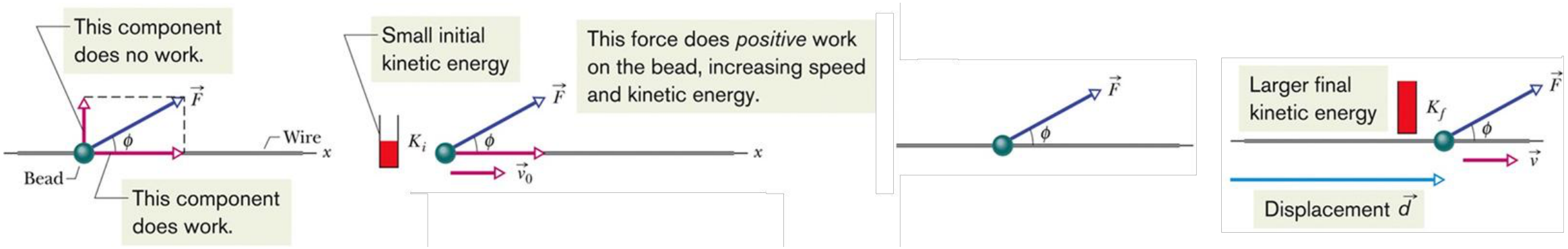
Note: only by the component of the force that is along d does the work

**The work can also be written as the dot product of the force and the displacement:**

$$W = \vec{F} \cdot \vec{d}$$



# Graphical Work-Force Relationship




A constant force $\vec{F}$ directed at angle $\phi$ to the displacement $\vec{d}$ of a bead on a wire accelerates the bead along the wire, changing the velocity of the bead from $\vec{v}_0$ to $\vec{v}$ . A "kinetic energy gauge" indicates the resulting change in the kinetic energy of the bead, from the value $K_i$ to the value $K_f$ .

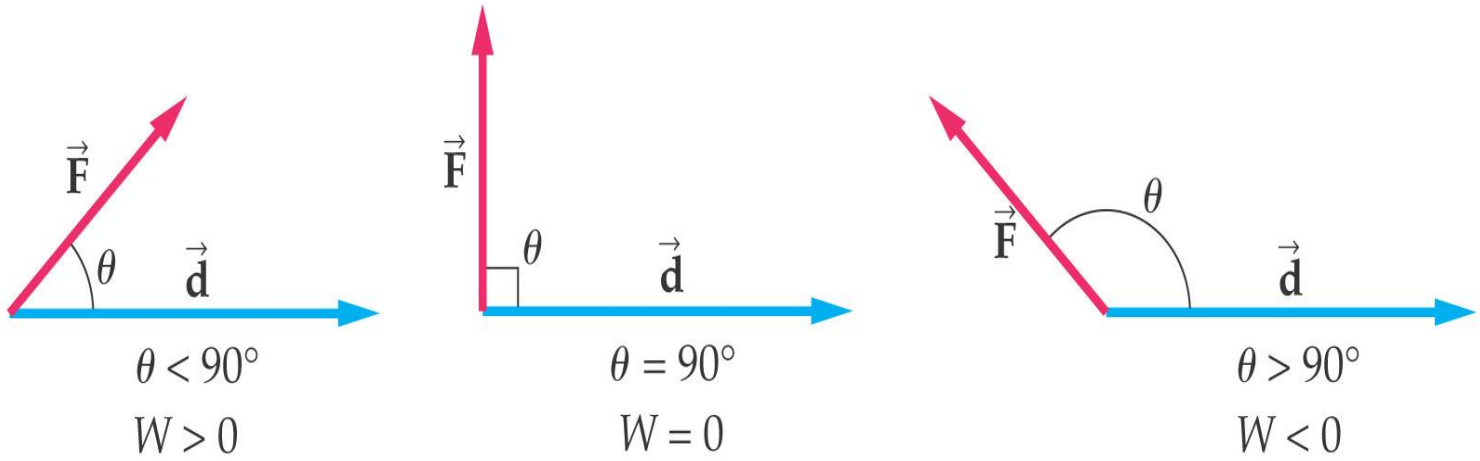
## Negative work and positive work

The work done may be **positive, zero, or negative,** depending on the angle between the force and the displacement:

*(i)* *Work is positive if the force has a component in the direction of motion*
$(-90 < \theta < 90)$

*(i)* *Work is zero if the force has no component in the direction of motion*
$(\theta = \pm 90^o)$

*(ii)* *Work is negative if the force has a component opposite to the direction of motion*
$(90^o < \theta < 270^o)$

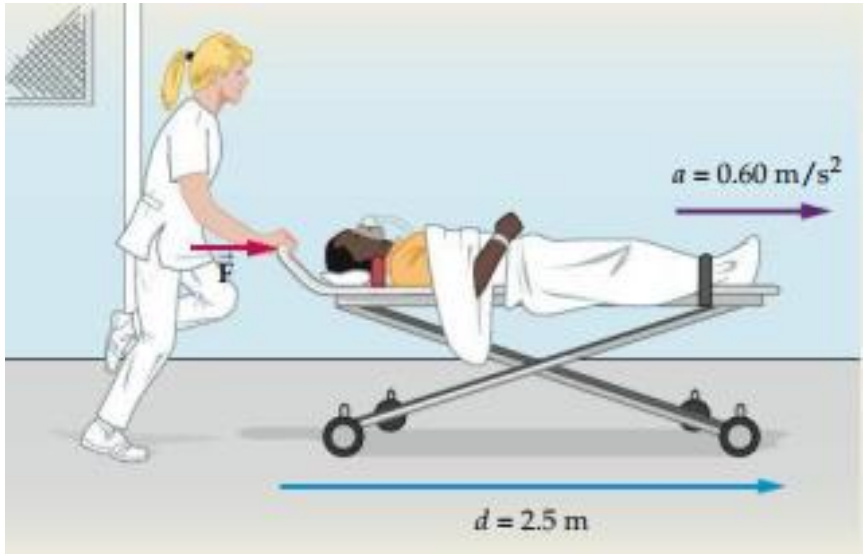


**Example 3.** An intern pushes a 72 kg patient on a 15 kg gurney, producing an acceleration of 0.60 m/s$^2$.

(a) How much work does the intern do by pushing the patient and gurney through a distance of 2.5 m? Assume the gurney moves without friction.

(b) How far must the intern push the gurney to do 140 J of work?

Answer: (a) W=130 J, (b) d= 2.7m




**SOLUTION**

**Part (a)**

1. First, find the force $F$ exerted by the intern: $F = ma = (72\text{ kg} + 15\text{ kg})(0.60\text{ m/s}^2) = 52\text{ N}$
2. The work done by the intern, $W$, is the force times the distance: $W = Fd = (52\text{ N})(2.5\text{ m}) = 130\text{ J}$

**Part (b)**

3. Use $W = Fd$ to solve for the distance $d$: $W = Fd$ therefore $d = \frac{W}{F} = \frac{140\text{ J}}{52\text{ N}} = 2.7\text{ m}$

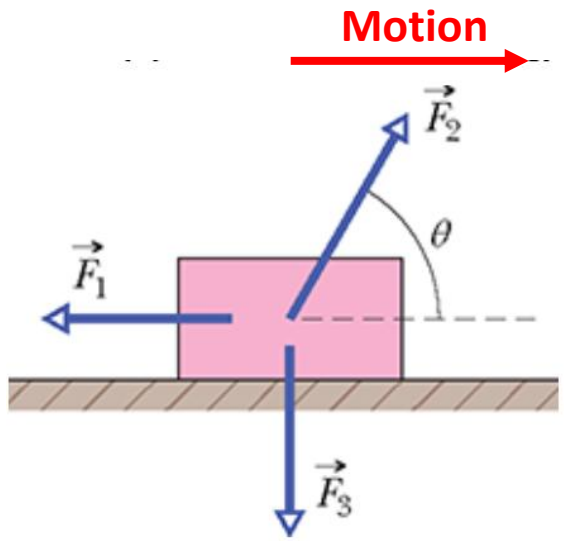
# Total Work

When more than one force acts on an object, the total work is the sum of the work done by each force separately. If $\vec{F}_1$ does work $W_1$, $\vec{F}_2$ does work $W_2$, $\vec{F}_3$ does work $W_3$, and so on

**The total work is :** $W_{total} = W_1 + W_2 + W_3 + \cdots = \sum W$

**Example 4.** Figure shows three forces applied to a trunk that moves leftward by 3.00 m over a frictionless floor. The force magnitudes are $F_1 = 5.00\ N$, $F_2 = 9.00\ N$, and $F_3 = 3.00\ N$, and the indicated angle is $\theta = 60.0°$ . During the displacement, (a) what is the net work done on the trunk by the three forces and (b) does the kinetic energy of the trunk increase or decrease?

Answer: (a) W=150 J, (b) increase



$$W_1 = F_1 d \cos\phi_1 = (5.00\,\text{N})(3.00\,\text{m})\cos 0° = 15.0\ \text{J}.$$

Force $\vec{F}_2$ makes an angle of 120° with the displacement, so

$$W_2 = F_2 d \cos\phi_2 = (9.00\,\text{N})(3.00\,\text{m})\cos 120° = -13.5\ \text{J}.$$

Force $\vec{F}_3$ is perpendicular to the displacement, so

$$W_3 = F_3 d \cos\phi_3 = 0 \text{ since } \cos 90° = 0.$$

The net work done by the three forces is

$$W = W_1 + W_2 + W_3 = 15.0\ \text{J} - 13.5\ \text{J} + 0 = +1.50\ \text{J}.$$

(b) If no other forces do work on the box, its kinetic energy increases by 1.50 J during the displacement.

**Example 5.** A car of mass 1550 kg coasts down a hill at an angle of $5.0^{o}$ below the horizontal. The car is acted on by three forces :

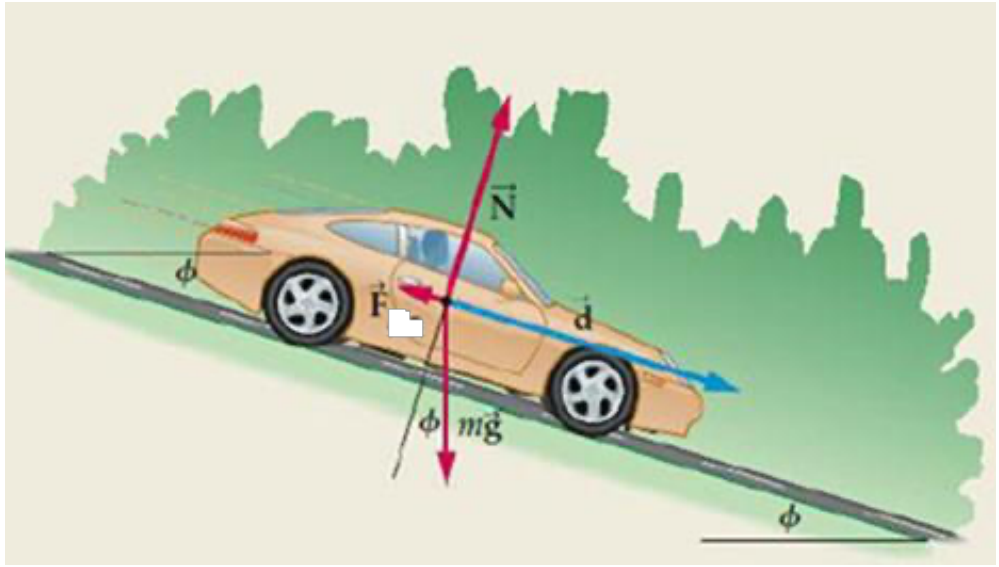
(i) the normal force **N** exerted by the road,

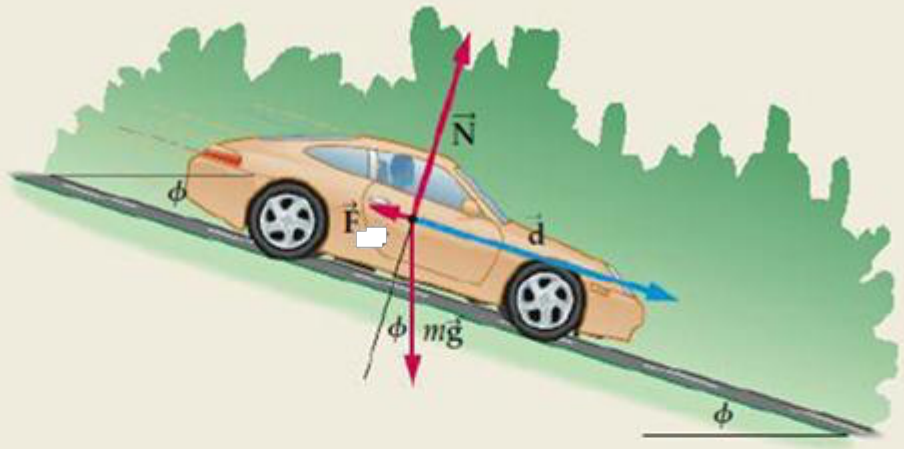
(ii) a force due to friction, $f$, and

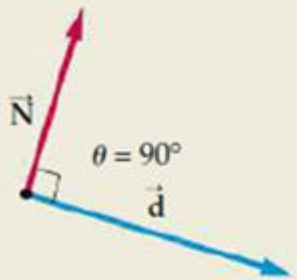
(iii) the force of gravity, mg.

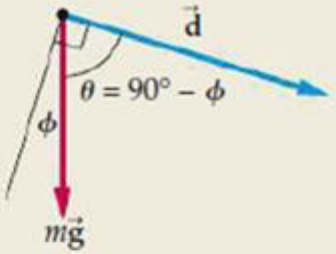
Find the work done by each of the forces and the total work done on the car as it travels a distance 20.4 m down the hill. The force due to friction is 15.0 N.

Answer: (a) W=26730 J









**STRATEGY**

For each force we calculate the work using $W = Fd\cos\theta$, where $\theta$ is the angle between that particular force and the displacement $\vec{d}$. The total work is the sum of the work done by each of the three forces.

**SOLUTION**

1. We start with the work done by the normal force, $\vec{N}$. From the figure we see that $\theta = 90°$ for this force: $W_N = Nd\cos\theta = Nd\cos 90° = Nd(0) = 0$

2. For the force ( $\theta = 180°$: $W_{air} = F_{\square}d\cos 180° = F_{\square}d(-1) = -F_{\square}d$

3. For gravity the angle $\theta$ is $\theta = 90° - \phi$, as indicated in the figure. Recall that $\cos(90° - \phi) = \sin\phi$ (see Appendix A): $W_{mg} = mgd\cos(90° - \phi) = mgd\sin\phi$

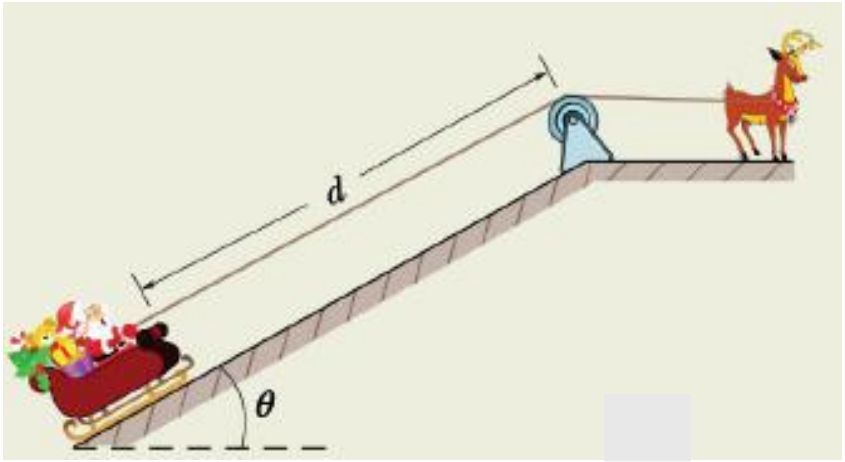
4. The total work is the sum of the individual works: $W_{total} = W_N + W_{\square} + W_{mg} = 0 - F_{\square}d + mgd\sin\phi$

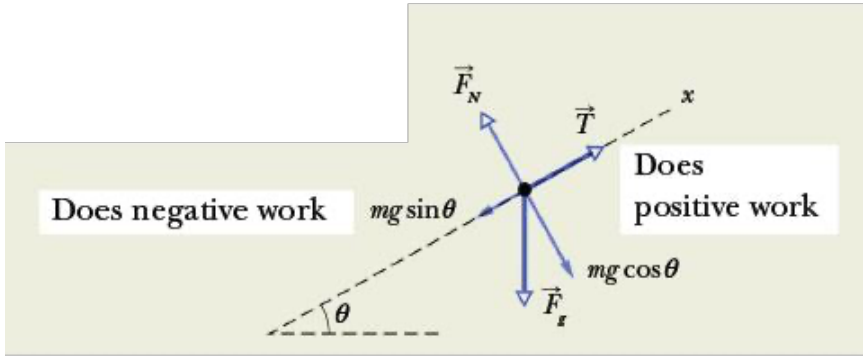
**Example 6.** In this problem an object is pulled along a ramp but the object starts and ends at rest and thus has no overall change in its kinetic energy (that is important). A rope pulls a 200 kg sleigh (which you may know) up a slope at incline angle $\theta$ = 30°, through distance $d$ = 20 m. The sleigh and its contents have a total mass of 200 kg. The snowy slope is so slippery that we take it to be frictionless.

(a) How much work is done by each force acting on the sleigh?

(b) Find the total work done on the sleigh

Answer: (a) $W_N = 0\ J$ J, $W_{Fgx} = -1.96 \times 10^4\ J$, $W_T = 1.96 \times 10^4\ J$ (b) $W_T = 0\ J$



***Work $W_N$ by the normal force.*** Let's start with this easy calculation. The normal force is perpendicular to the slope and thus also to the sleigh's displacement. Thus the normal force does not affect the sleigh's motion and does zero work. To be more formal, we can apply Eq. 7.2.5 to write

$$W_N = F_N d \cos 90° = 0. \qquad \text{(Answer)}$$

***Work $W_g$ by the gravitational force.*** We can find the work done by the gravitational force in either of two ways (you pick the more appealing way). From an earlier discussion about ramps (Sample Problem 5.3.2 and Fig. 5.3.6), we know that the component of the gravitational force along the slope has magnitude $mg \sin\theta$ and is directed down the slope. Thus the magnitude is

$$F_{gx} = mg \sin\theta = (200\text{ kg})(9.8\text{ m/s}^2) \sin 30° = 980\text{ N}.$$

The angle $\phi$ between the displacement and this force component is 180°. So we can apply Eq. 7.2.5 to write

$$W_g = F_{gx} d \cos 180° = (980\text{ N})(20\text{ m})(-1) = -1.96 \times 10^4\text{ J}. \qquad \text{(Answer)}$$

The negative result means that the gravitational force removes energy from the sleigh.

***Work $W_T$ by the rope's force.*** We have two ways of calculating this work. The quicker way is to use the work–kinetic energy theorem of Eq. 7.2.8 ($\Delta K = W$), where the net work $W$ done by the forces is $W_N + W_g + W_T$ and the change $\Delta K$ in the kinetic energy is just zero (because the initial and final kinetic energies are the same—namely, zero). So, Eq. 7.2.8 gives us

$$0 = W_N + W_g + W_T = 0 - 1.96 \times 10^4\text{ J} + W_T$$

and

$$W_T = 1.96 \times 10^4\text{ J}. \qquad \text{(Answer)}$$

Instead of doing this, we can apply Newton's second law for motion along the $x$ axis to find the magnitude $F_T$ of the rope's force. Assuming that the acceleration along the slope is zero (except for the brief starting and stopping), we can write

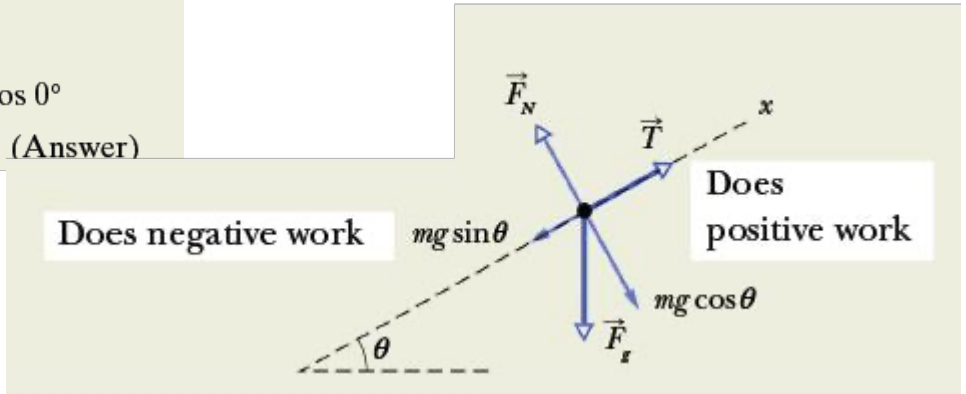
$$F_{\text{net},x} = ma_x,$$
$$F_T - mg \sin 30° = m(0),$$

to find

$$F_T = mg \sin 30°.$$

This is the magnitude. Because the force and the displacement are both up the slope, the angle between those two vectors is zero. So, we can now write Eq. 7.2.5 to find the work done by the rope's force:

$$W_T = F_T d \cos 0° = (mg \sin 30°) d \cos 0° = (200\text{ kg})(9.8\text{ m/s}^2)(\sin 30°)(20\text{ m}) \cos 0° = 1.96 \times 10^4\text{ J}. \qquad \text{(Answer)}$$



# Work-Energy Relationship

1. Account for changes in kinetic energy by saying energy has been transferred to or from the object
2. In a transfer of energy via a force, **work** is:
   Done on the object by the force

Work *W* is energy transferred to or from an object by means of a force acting on the object. Energy transferred to the object is positive work, and energy transferred from the object is negative work. Displacement MUST take place in order for work to be done.

Example :

To do work on an object, energy must be transferred
Throwing a baseball does work
Pushing an immovable wall does not do work

# Work - Kinetic Energy Theorem

**Work-Kinetic Energy Theorem states**: The total work done on an object is equal to its change in kinetic energy.

$$W_{\text{total}} = \Delta K = \frac{1}{2}mv_{\text{f}}^2 - \frac{1}{2}mv_{\text{i}}^2$$

**Example 7.** A boy exerts a force of 11 N at 29° above the horizontal on a 6.4 kg sled. Find (a) the work done by the boy and (b) the final speed of the sled after in moves 2 m, assuming the sled starts with an initial speed of 0.5 m/s and slides horizontally without friction.

Answers: W = 19.2 J, $V_f$ = 2.50m/s

**SOLUTION**

**Part (a)**

1. The work done by the boy is $(F\cos\theta)d$, where $\theta = 29.0°$. This is also the total work done on the sled:

$$W_{boy} = (F\cos\theta)d$$
$$= (11.0\text{ N})(\cos 29.0°)(2.00\text{ m}) = 19.2\text{ J} = W_{total}$$

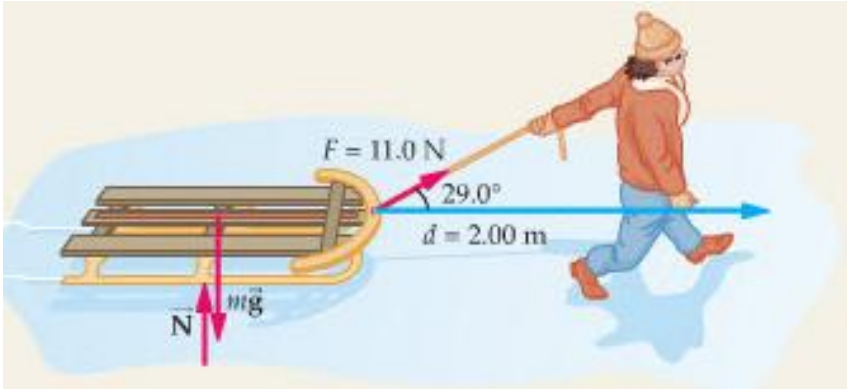
**Part (b)**

2. Use the work–energy theorem to solve for the final speed:

$$W_{total} = \Delta K = \tfrac{1}{2}mv_f^2 - \tfrac{1}{2}mv_i^2$$
$$\tfrac{1}{2}mv_f^2 = W_{total} + \tfrac{1}{2}mv_i^2$$
$$v_f = \sqrt{\frac{2W_{total}}{m} + v_i^2}$$

3. Substitute numerical values to get the final answer:

$$v_f = \sqrt{\frac{2(19.2\text{ J})}{6.40\text{ kg}} + (0.500\text{ m/s})^2}$$
$$= 2.50\text{ m/s}$$




**Example 8.** How much work is required for 74 kg sprinter to accelerate from rest to 2.2 m/s?

Answer: W = 180J

$$W = \Delta K = \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2 = \frac{1}{2}(74)(2.2)^2 - 0 = 180\,J$$

# 7.3 Work Done By Gravitational Force

The work $W_g$ done by the gravitational force $\vec{F}_g$ on a particle-like object of mass  as the object moves through a displacement $\vec{d}$ is given by

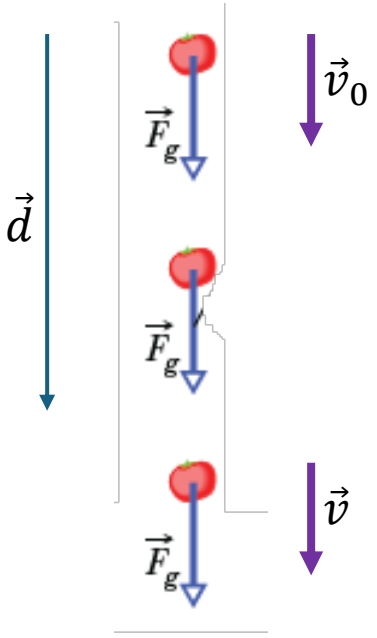
$$W_g = mgd\cos\phi$$

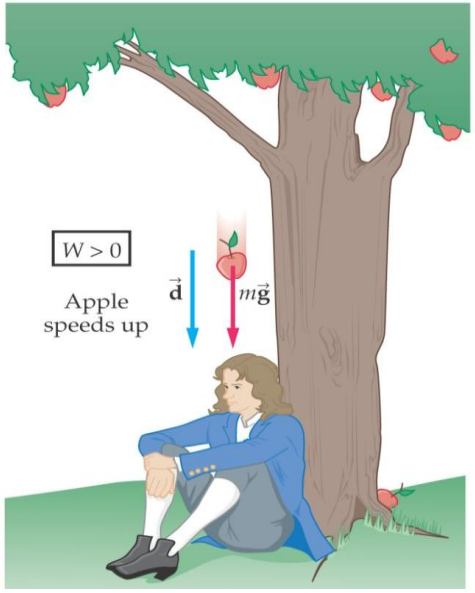
- For a falling object:

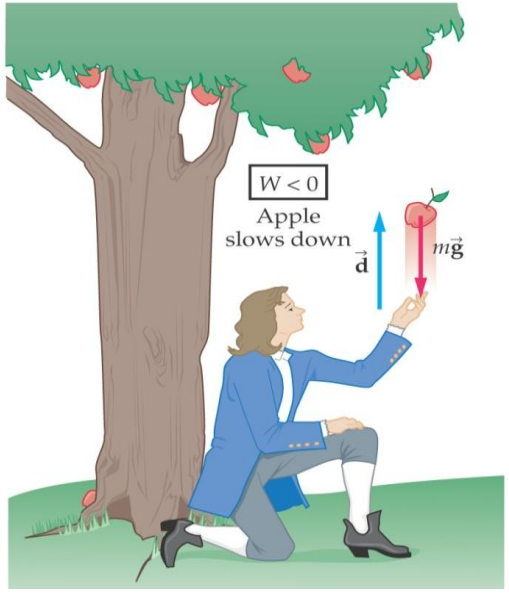
$$W_g = mgd\cos 0° = mgd\,(+1) = +mgd.$$

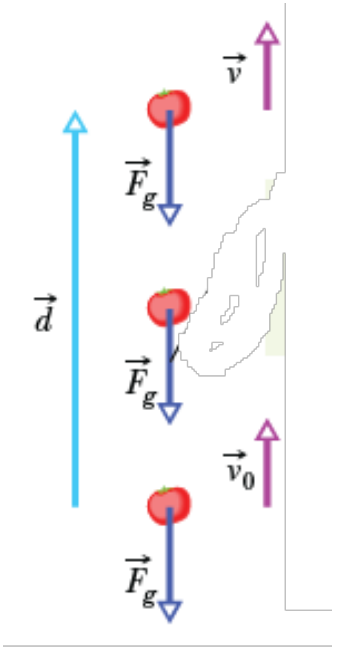
- For a rising object:

$$W_g = mgd\cos 180° = mgd\,(-1) = -mgd.$$



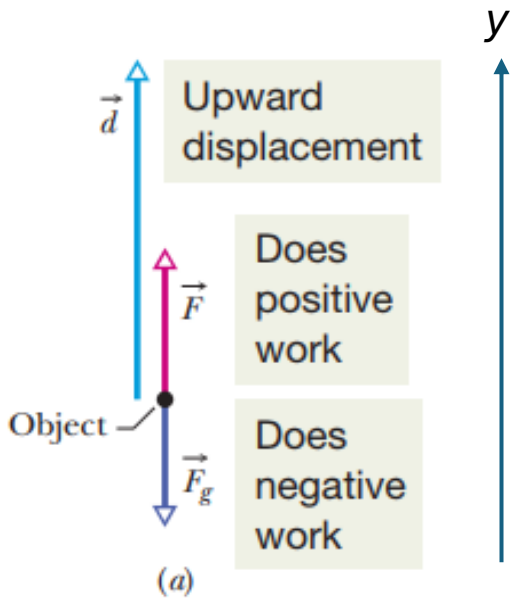



# Work Done in Lifting and Lowering an Object

Now suppose we lift a particle-like object by applying a vertical force $F$ to it with **constant speed**. During the upward displacement, Our applied force tends to transfer energy to the object while the gravitational force tends to transfer energy from it.




$$W_{tot} = W_F - W_g = K_f - K_i$$

Because the speed is constant, the change in kinetic energy is zero (work done in lifting and lowering; $K_f = K_i$).

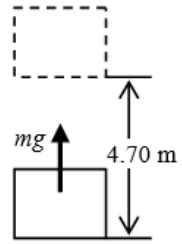
$$W_F - W_g = 0$$

$$W_F = W_g = mgd$$

**Example 9.** Children in a tree house lift a small dog in a basket 4.70 m up to their house with constant speed. If it takes 201 J of work to do this, what is the combined mass of the dog and basket?
(Answer: 4. 36 kg)

**Solution:** Apply equation 7-1: $W = Fd = mgd$

Now solve for $m$: $m = \frac{W}{gd} = \frac{201\ \text{J}}{(9.81\ \text{m/s}^2)(4.70\ \text{m})} = \boxed{4.36\ \text{kg}}$

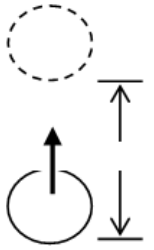



**Problem 10.** Early one October, you go to a pumpkin patch to select your Halloween pumpkin. You lift the 3.2 kg pumpkin to a height of 1.2 m, **then carry it 50.0 m** ( on level ground ) to check-out stand with constant speed. (a) Calculate the work you do on the pumpkin as you lift it from the ground. (b) How much work do you do on the pumpkin as you carry it from the field?
Answer : a) Work =37.7J , b) Work = zero

**Solution: 1. (a)** Apply equation 7-1 directly: $W = mgd$

$= (3.2\ \text{kg})(9.81\ \text{m/s}^2)(1.2\ \text{m}) = \boxed{38\ \text{J}}$

**2. (b)** The force is perpendicular to the displacement so $W = \boxed{0}$.



# 7.4 Work Done by a Spring Force

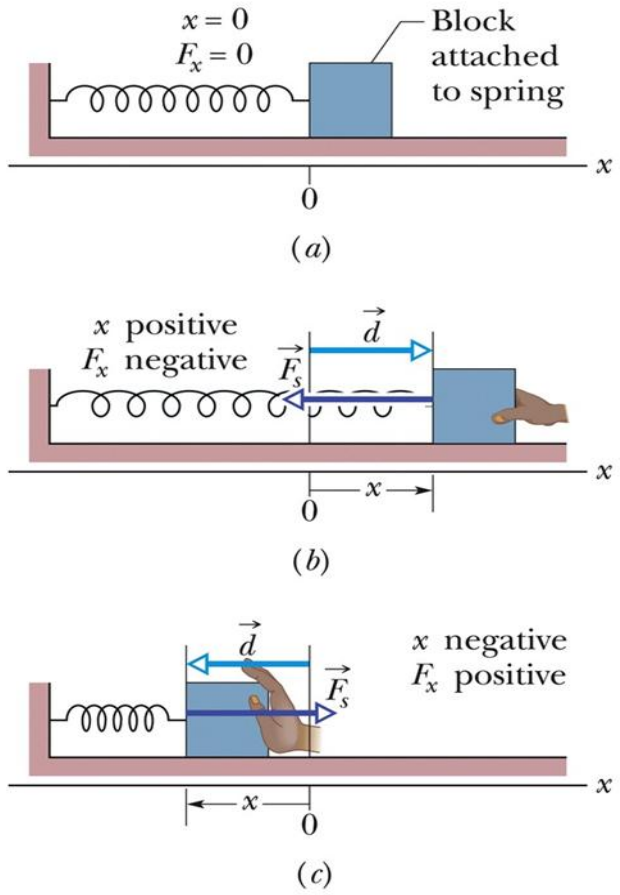
## The spring Force

A **spring force** is the variable force from a spring

- Figure (a) shows the spring in its **relaxed state**: since it is neither compressed nor extended, no force is applied
- If we stretch or extend the spring it resists, and exerts a restoring force that attempts to return the spring to its relaxed state

The spring force is given by **Hooke's law:** $\vec{F}_s = -k\vec{d}$

For a spring along the *x-axis,* we can write: $F_x = -kx$




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- The negative sign represents that the force always opposes the displacement
- The **spring constant** *k* is a is a measure of the stiffness of the spring
- This is a variable force (function of position) and it exhibits a linear relationship between *F* and *d*

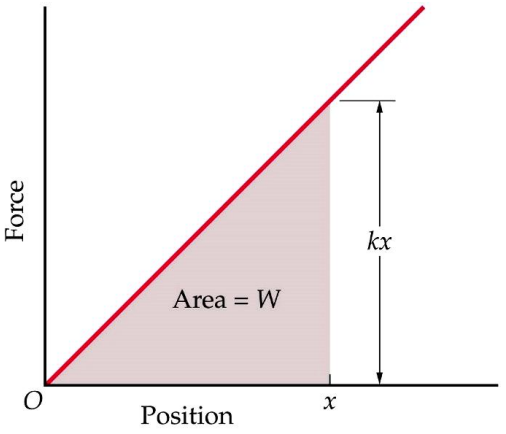
# Work Done by Spring Forces (variable force)

To find the work done by the spring force as the block moves, let us make two simplifying assumptions about the spring.
(1) It is massless; that is, its mass is negligible relative to the block's mass.
(2) It is an ideal spring; that is, it obeys Hooke's law exactly. Let us also assume that the contact between the block and the floor is frictionless

$$W_s = \int_{x_i}^{x_f} -F_x dx. \quad \Longrightarrow \quad W_s = \frac{1}{2}kx_i^2 - \frac{1}{2}kx_f^2$$

For an initial position of $x = 0$, the work done by a spring force

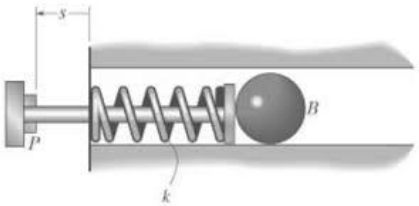
$$W_s = -\frac{1}{2}kx^2$$




Work is positive if the block ends up closer to the relaxed position ($x = 0$) than it was initially. It is negative if the block ends up farther away from $x = 0$. It is zero if the block ends up at the same distance from $x = 0$.

**Example 11.** The spring in a pinball launcher has a force constant of 405 N/m. How Much work is required to compress the spring a distance of 3.00 cm?

$Answer: W = 0.18\ J$



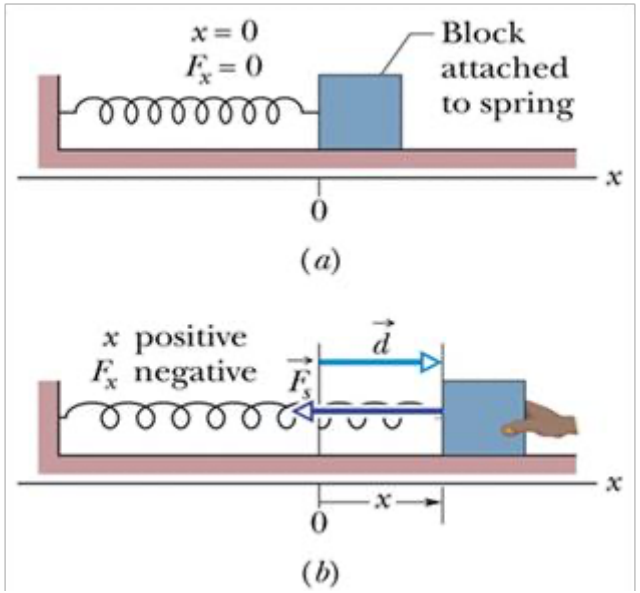



**SOLUTION**

$$W = \tfrac{1}{2}kx^2 = \tfrac{1}{2}(405\ \mathrm{N/m})(0.0300\ \mathrm{m})^2 = 0.182\ \mathrm{J}$$

**Example 12.** A spring and block are in the arrangement of figure. When the block is pulled out to *x* = +4.0 cm, we must apply a force of magnitude 360 N to hold it there. We pull the block to *x* = 11 cm and then release it. How much work does the spring do on the block as the block moves from *xi* = +5.0 cm to *x* = +3.0 cm.

$Answer: k = 9.0 \times 10^3 \frac{N}{m},\ W = 0.18\ J$




we see that the work done by the spring force is given by $W_s = \frac{1}{2}k(x_i^2 - x_f^2)$.

The fact that 360 N of force must be applied to pull the block to $x$ = +4.0 cm indicates that the spring constant is

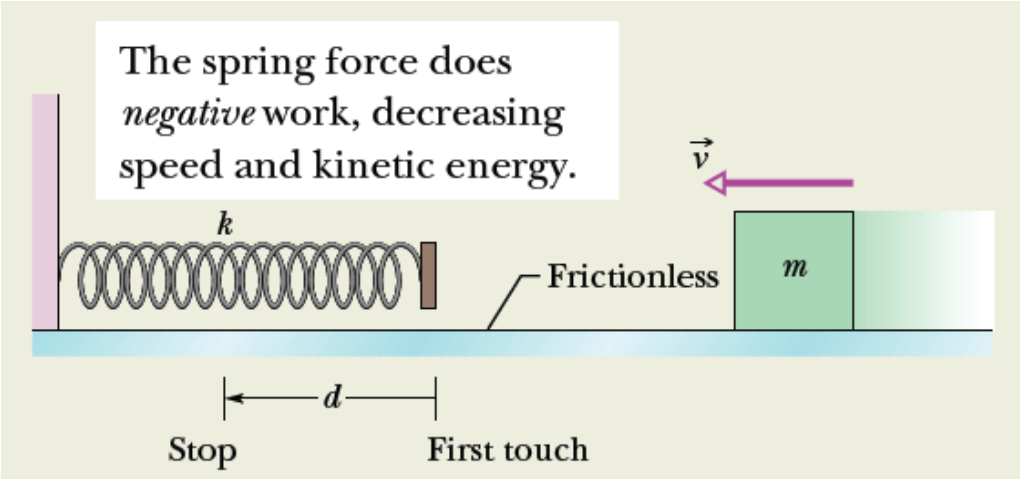
$$k = \frac{360\ \text{N}}{4.0\ \text{cm}} = 90\ \text{N/cm} = 9.0\times10^3\ \text{N/m}.$$

When the block moves from $x_i = +5.0$ cm to $x = +3.0$ cm, we have

$$W_s = \frac{1}{2}(9.0\times10^3\ \text{N/m})[(0.050\ \text{m})^2 - (0.030\ \text{m})^2] = 7.2\ \text{J}.$$

**Example 13.** In figure, a cumin canister of mass $m$ = 0.40 kg slides across a horizontal frictionless counter with speed $v$ = 0.50 m/s. It then runs into and compresses a spring of spring constant $k$ = 750 N/m. When the canister is momentarily stopped by the spring, by what distance $d$ is the spring compressed?

$Answer: d = 1.2 \times 10^{-2}\ cm$




***Calculations:*** Putting the first two of these ideas together, we write the work–kinetic energy theorem for the canister as

$$K_f - K_i = -\tfrac{1}{2}kd^2.$$

Substituting according to the third key idea gives us this expression:

$$0 - \tfrac{1}{2}mv^2 = -\tfrac{1}{2}kd^2.$$

Simplifying, solving for $d$, and substituting known data then give us

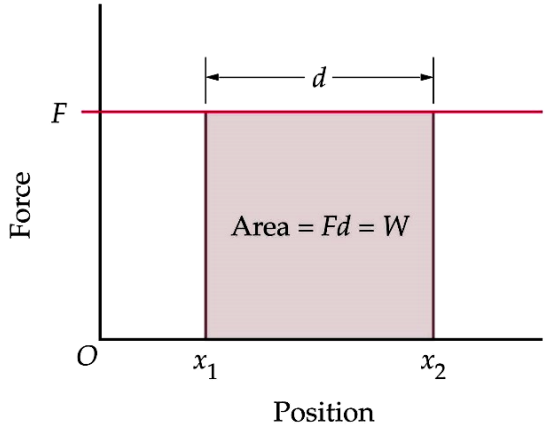
$$d = v\sqrt{\frac{m}{k}} = (0.50\ \text{m/s})\sqrt{\frac{0.40\ \text{kg}}{750\ \text{N/m}}}$$

$$= 1.2 \times 10^{-2}\ \text{m} = 1.2\ \text{cm}. \qquad \text{(Answer)}$$

# 7.5 Work Done by a General variable Force

## Work done by a constant force

A constant force *F* acting through a distance *d* does a work. we can graphically interpret the work done (*W = F d*) as the area of a rectangle *F* tall and *d* wide.

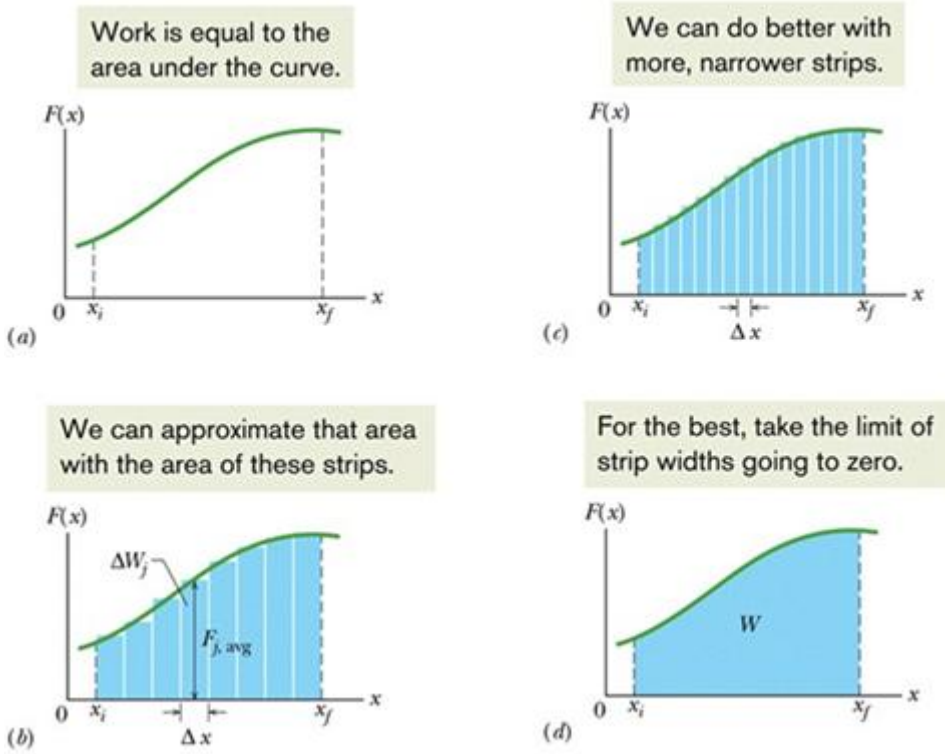



## Work with varying forces

If a force varies continuously with position, we can approximate it with a series of constant values that follow the shape of the curve

The work done by a force in moving an object from $x_i$ to $x_f$ is equal to the corresponding area between the force curve and the *x* axis.

$$W = \int_{x_i}^{x_f} F(x)\,dx$$



# 7.6 Power

- **Power** is the time rate at which a force does work or changes energy.
- A force does $W$ work in a time $\Delta t$; the **average power** due to the force is:

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

- The SI unit for power is the watt (W): 1 W = 1 J/s
- Therefore work-energy can be written as (power) × (time) e.g. kWh, the kilowatt-hour
- **1 horsepower = 1 hp = 746 W**

- The **instantaneous power** at a particular time is:

$$P = \frac{dW}{dt}$$

- Solve for the instantaneous power using the definition of work:

$$P = \frac{dW}{dt} = \frac{F\cos\phi\, dx}{dt} = F\cos\phi\left(\frac{dx}{dt}\right),$$

$$P = Fv\cos\phi.$$

$$\boldsymbol{P = \vec{F}\cdot\vec{v}}$$

**Example 14.** A 5 Kg Cart is pushed by a 30 N force against friction for a distance of 10 m in 5 seconds. Determine the Power needed to move the cart.

Answer : P = 60 Watts

$$P = \frac{W}{t} = \frac{300J}{5s} = 60\ Watts$$

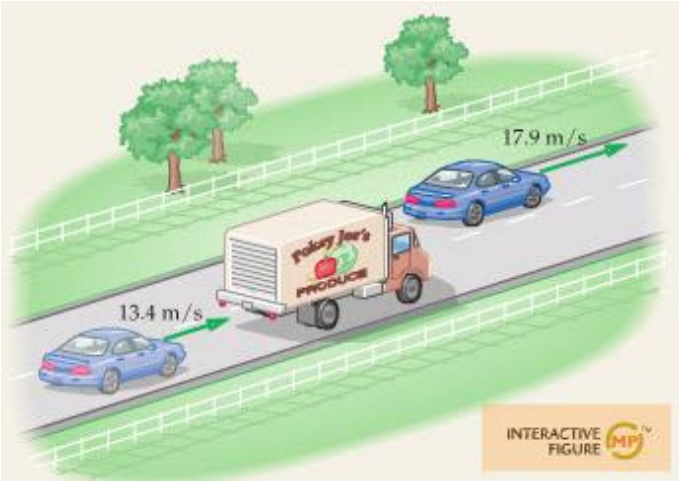
$$W = Fd = (30N)(10m) = 300J$$

**Example 15.** To pass a slow-moving truck you want your $1.3 \times 10^3$ kg car to accelerate from 13.4 m/s to 17.9 m/s in 3 seconds. What is the minimum power required for this pass.

Answers : $\Delta K = 9.16 \times 10^4\ J$, $P = 3.05 \times 10^4$ $Watt$

$$\Delta K = \tfrac{1}{2}mv_f^2 - \tfrac{1}{2}mv_i^2 = \tfrac{1}{2}(1.30 \times 10^3\ \text{kg})(17.9\ \text{m/s})^2 - \tfrac{1}{2}(1.30 \times 10^3\ \text{kg})(13.4\ \text{m/s})^2 = 9.16 \times 10^4\ \text{J}$$

$$P = \frac{W}{t} = \frac{\Delta K}{t} = \frac{9.16 \times 10^4\ \text{J}}{3.00\ \text{s}} = 3.05 \times 10^4\ \text{W} = 40.9\ \text{hp}$$



# Chapter 7 Summary

**Kinetic Energy:** The energy associated with motion

**Work:** Energy transferred to or from an object via a force. Can be positive or negative

**Work Done by a Constant Force:**

The **net work** is the sum of individual works

**Work and Kinetic Energy Conservation:**

**Work Done by the Gravitational Force**

**Work Done in Lifting and Lowering an Object**

# Chapter 7 Summary

**Spring Force:** Relaxed state: applies no force. Spring constant $k$ measures stiffness

**Spring Force:** For an initial position $x = 0$:

**Work Done by a Variable Force**

- Found by integrating the constant-force work equation

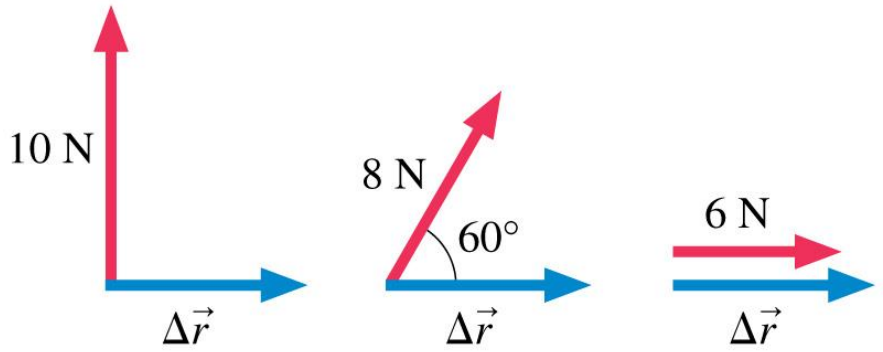
**Power**

- The rate at which a force does work on an object
- Average power:

# Additional Exercises

Which force does the most work?

1. **The 6 N force.**
2. The 8 N force.
3. The 10 N force.
4. They all do the same amount of work.




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A crane lowers a steel girder into place at a construction site. The girder moves with constant speed. Consider the work $W_g$ done by gravity and the work $W_T$ done by the tension in the cable. Which of the following is correct?

1. $W_g$ is positive and $W_T$ is positive.
2. $W_g$ is negative and $W_T$ is negative.
3. $W_g$ is positive and $W_T$ is negative.
4. $W_g$ and $W_T$ are both zero.
5. $W_g$ is negative and $W_T$ is positive.

A crane lowers a steel girder into place at a construction site. The girder moves with constant speed. Consider the work $W_g$ done by gravity and the work $W_T$ done by the tension in the cable. Which of the following is correct?

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3. **$W_g$ is positive and $W_T$ is negative.**
4. $W_g$ and $W_T$ are both zero.
5. $W_g$ is negative and $W_T$ is positive.

**Example :** In a gravity escape system (GES), an enclosed lifeboat on a large ship is deployed by letting it slide down a ramp and then continuing in free fall to the water below. Suppose a 4970-kg lifeboat slides a distance of 5.00 m on a ramp, dropping through a vertical height of 2.50 m. How much work does gravity do on the boat?

*Answer* $W = 122\ kJ$

**SOLUTION**

1. First, find the component of $\vec{F} = m\vec{g}$ in the direction of motion:

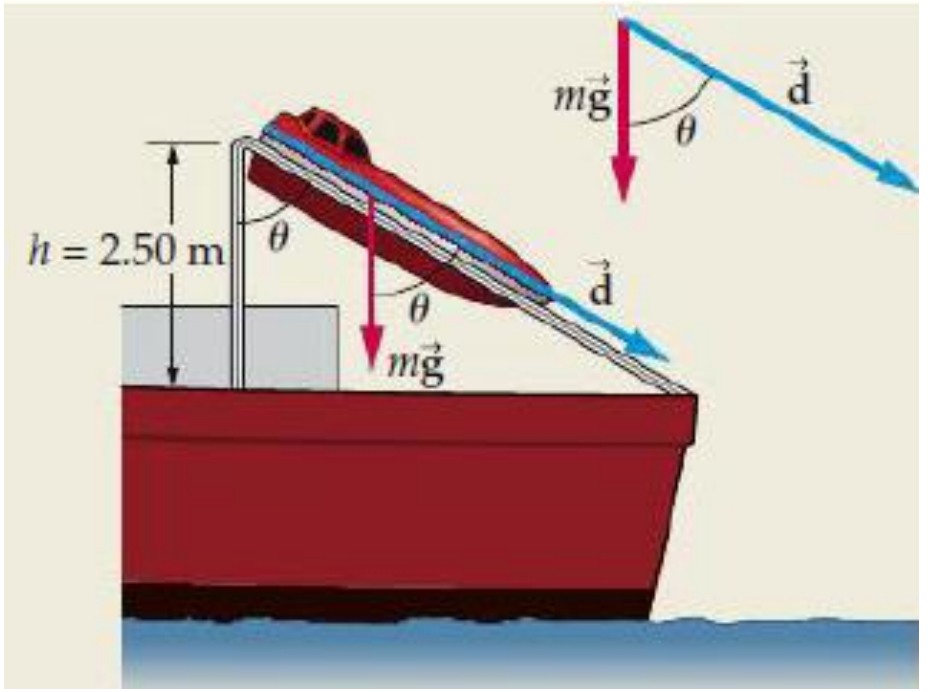
$$F\cos\theta = (mg)\left(\frac{h}{d}\right)$$

$$= (4970\text{ kg})(9.81\text{ m/s}^2)\left(\frac{2.50\text{ m}}{5.00\text{ m}}\right) = 24{,}400\text{ N}$$

$$W = (F\cos\theta)d = (24{,}400\text{ N})(5.00\text{ m}) = 122{,}000\text{ J}$$

$$W = Fd\cos\theta = (mg)(d)\left(\frac{h}{d}\right)$$

$$= mgh = (4970\text{ kg})(9.81\text{ m/s}^2)(2.50\text{ m}) = 122{,}000\text{ J}$$



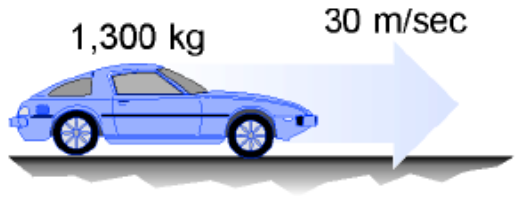
# Exercises

EXERCISE: 7-1 (Assignment)

**Problem:** A farmhand pushes a 26 kg bale of hay 3.9 m across the floor of a barn. If she exerts a horizontal force of 88 N on the bay, how much work has she done? (Answer 343.2)
Answer : Work = 343 J

**Problem**: A car with a mass of 1,300 kg is going straight ahead at a speed of 30 m/sec (67 mph). The brakes can supply a force of 9,500 N.

- Calculate:
  a) The kinetic energy of the car. ( KE: 585000 J )
  b) The distance it takes to stop. ( 61.58 m)




**Problem:** How much work is needed for a 73 kg runner to accelerate from rest to 7.7 m/s?
Answer : (Work=2164 J )

**Problem:** A 9.5 g bullet has a speed of 1.3 km/s. (a) What is its kinetic energy in Joules? (b) What is the bullet's kinetic energy if its speed is halved? (c) If its speed is doubled?
Answers: ( 8027 J, 2007 J; 32110 J )

# Exercises

**Exercise:** At what rate is work being done when a 26 N horizontal force moves a book 2.5 m horizontally in 13 s?

(Answer: $W = 65\,J \Rightarrow Power = 5$ Watts)

**Exercise:** What is the power of a machine that can produce 3600 J of work in 2 minutes?
(Answer: $Power = 30\,watt$ )

**Exercise:** How much work is done by a 25000-watt car engine in 5 minutes?

(Answer : $75\times 10^5$ J)

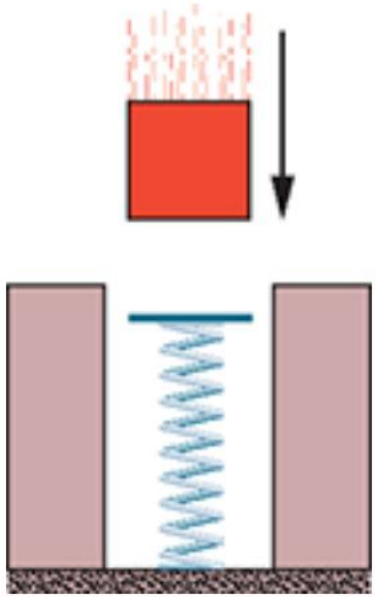
**Example:** A spring is hanged vertically from the ceiling of the room. When a block of mass 7 kg is hanged from the lower end, the spring is stretched by 14 cm. calculate the spring constant of this spring

(Answer: $\mathrm{k} = 490.5\ N/m$ )

**Example:** A 4.1 kg box of books is lifted vertically from rest a distance of 1.6 m with a constant upward applied force of 52.7 N. Find the work done by the applied force, the work done by gravity, and the final speed of the box.

(Answer: $Work = 84.32J$ , $Work\ g = -64.4\,J$ , $vf = 6.4\,m/s$ )

**62** A 250 g block is dropped onto a relaxed vertical spring that has a spring constant of $k$ = 2.5 N/cm (Fig. 7.31). The block becomes attached to the spring and compresses the spring 12 cm before momentarily stopping. While the spring is being compressed, what work is done on the block by (a) the gravitational force on it and (b) the spring force? (c) What is the speed of the block just before it hits the spring? (Assume that friction is negligible.) (d) If the speed at impact is doubled, what is the maximum compression of the spring?



62. (a) The compression of the spring is $d$ = 0.12 m. The work done by the force of gravity (acting on the block) is, by Eq. 7.3.1,

$$W_1 = mgd = (0.25\text{ kg})\left(9.8\text{ m/s}^2\right)(0.12\text{ m}) = 0.29\text{ J}.$$

(b) The work done by the spring is, by Eq. 7.4.7,

$$W_2 = -\frac{1}{2}kd^2 = -\frac{1}{2}(250\text{ N/m})(0.12\text{ m})^2 = -1.8\text{ J}.$$

(c) The speed $v_i$ of the block just before it hits the spring is found from the work-kinetic energy theorem (Eq. 7.3.4):

$$\Delta K = 0 - \frac{1}{2}mv_i^2 = W_1 + W_2,$$

which yields

$$v_i = \sqrt{\frac{(-2)(W_1 + W_2)}{m}} = \sqrt{\frac{(-2)(0.29\text{ J} - 1.8\text{ J})}{0.25\text{ kg}}} = 3.5\text{ m/s}.$$