Chapter 6

Work and Kinetic Energy

Introduction

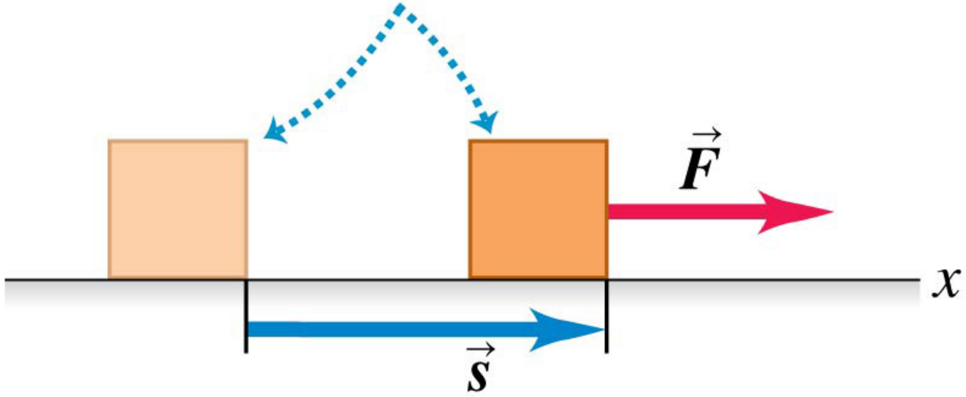
- A baseball pitcher does work with his throwing arm to give the ball a property called **kinetic energy**.
- In this chapter, the introduction of the concepts of *work*, *energy*, and the *conservation of energy* will allow us to deal with problems in which Newton's laws alone aren't enough.

Work

- A force on a body does *work* if the body undergoes a displacement.

These people are doing work as they push on the car because they exert a force on the car as it moves.

If a body moves through a displacement $\vec{s}$ while a constant force $\vec{F}$ acts on it in the same direction ...



... the work done by the force on the body is $W = Fs$.

Units of work

- The SI unit of work is the **joule** (named in honor of the 19th-century English physicist James Prescott Joule).
- Since $W = Fs$, the unit of work is the unit of force multiplied by the unit of distance.
- In SI units:

$$1 \text{ joule} = (1 \text{ newton})\,(1 \text{ meter}) \text{ or } 1 \text{ J} = 1 \text{ N} \cdot \text{m}$$

- If you lift an object with a weight of 1 N a distance of 1 m at a constant speed, you do 1 J of work on it.

Work done by a constant force

- The work done by a constant force acting at an angle ϕ to the displacement is:

Work done on a particle by **constant force** $\vec{F}$ during **straight-line displacement** $\vec{s}$

$$W = \underset{\text{Magnitude of } \vec{F}}{F}\,\underset{\text{Magnitude of } \vec{s}}{s}\cos\underset{\text{Angle between } \vec{F} \text{ and } \vec{s}}{\phi}$$

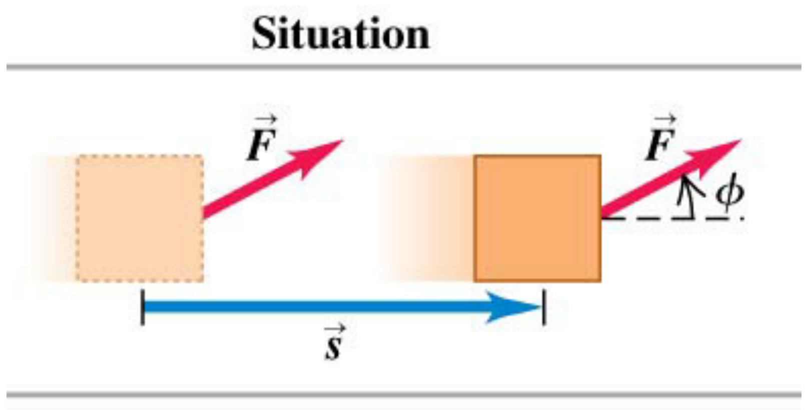
- This can be written more compactly as:

Work done on a particle by **constant force** $\vec{F}$ during **straight-line displacement** $\vec{s}$

$$W = \underbrace{\vec{F} \cdot \vec{s}}_{\text{Scalar product (dot product) of vectors } \vec{F} \text{ and } \vec{s}}$$

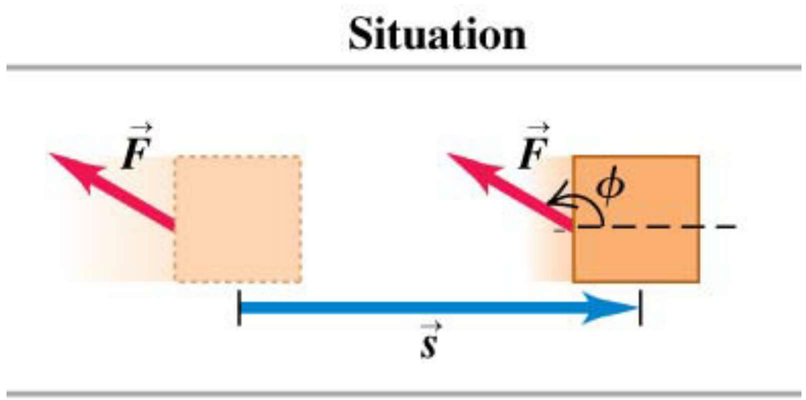
Positive work

- When the force has a component in the direction of the displacement, work is *positive*.



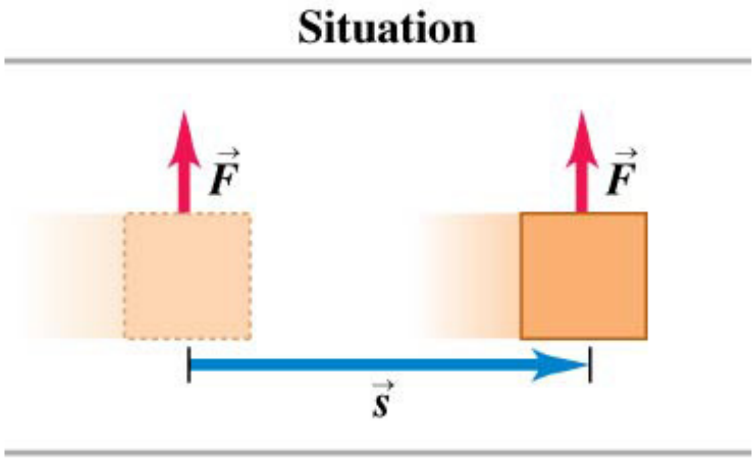
Negative work

- When the force has a component opposite to the direction of the displacement, work is *negative*.



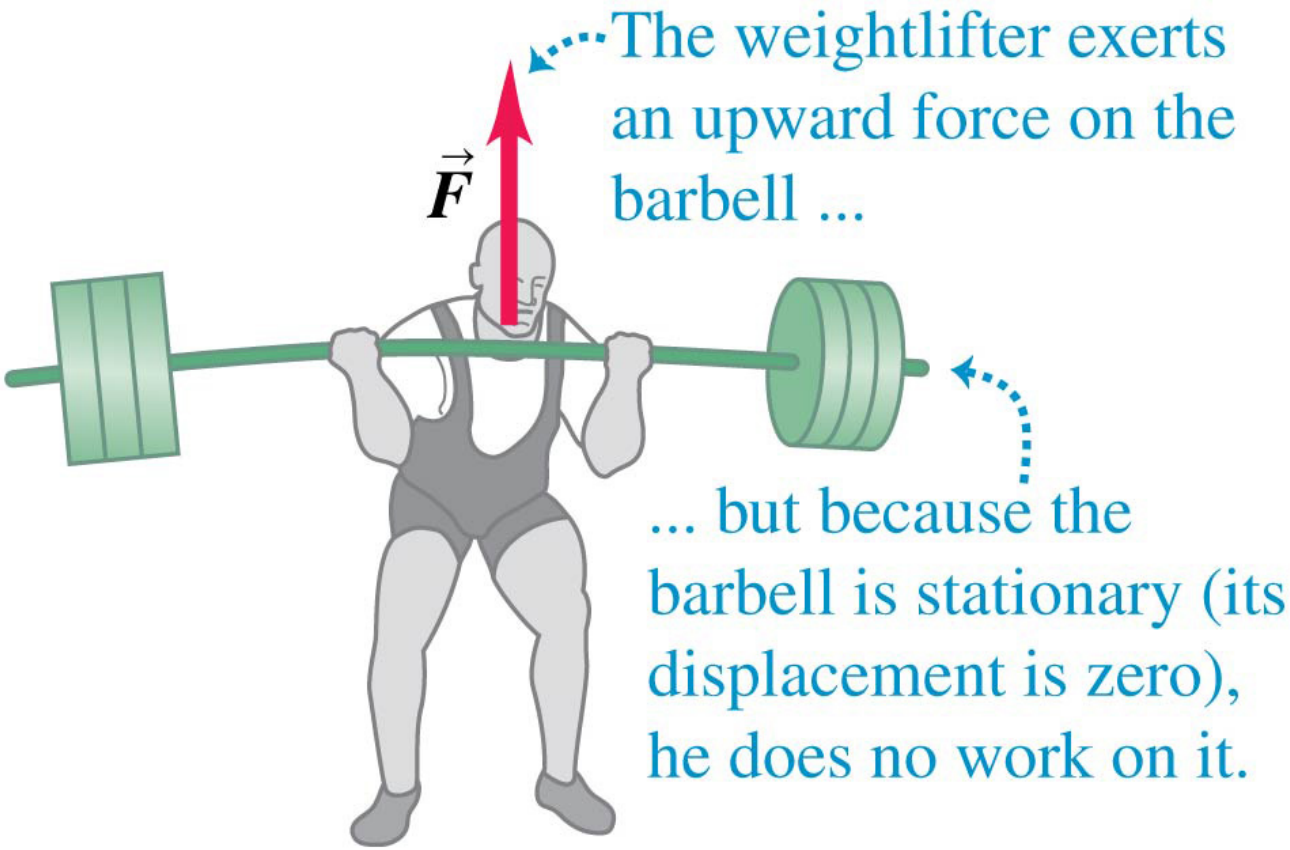
Zero work

- When the force is perpendicular to the direction of the displacement, the force does *no* work on the object.



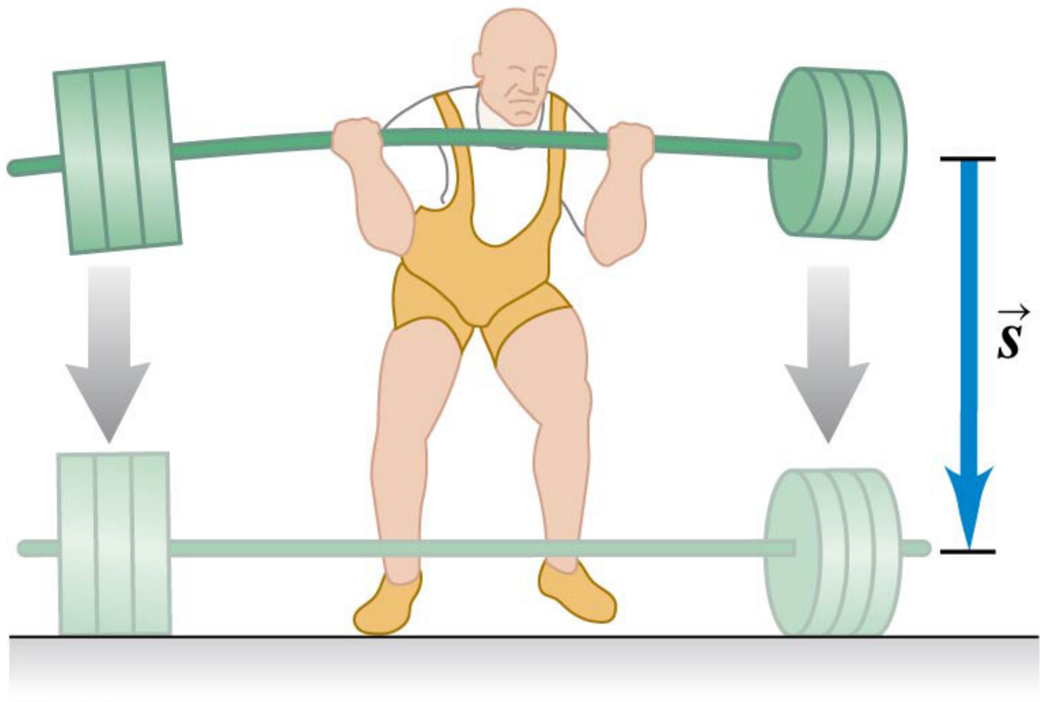
Zero work

- A weightlifter does no work on a barbell as long as he holds it stationary.

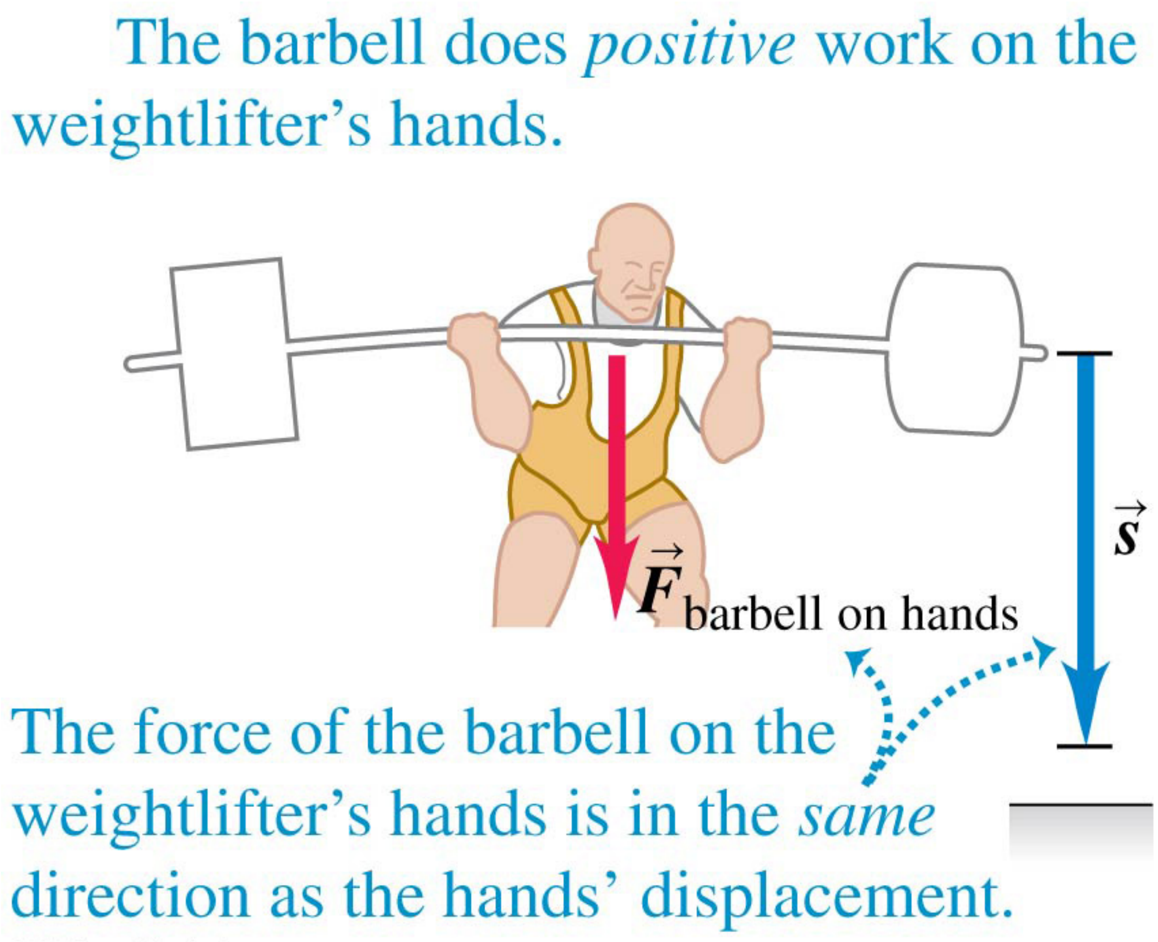


Lowering the barbell to the floor: Slide 1

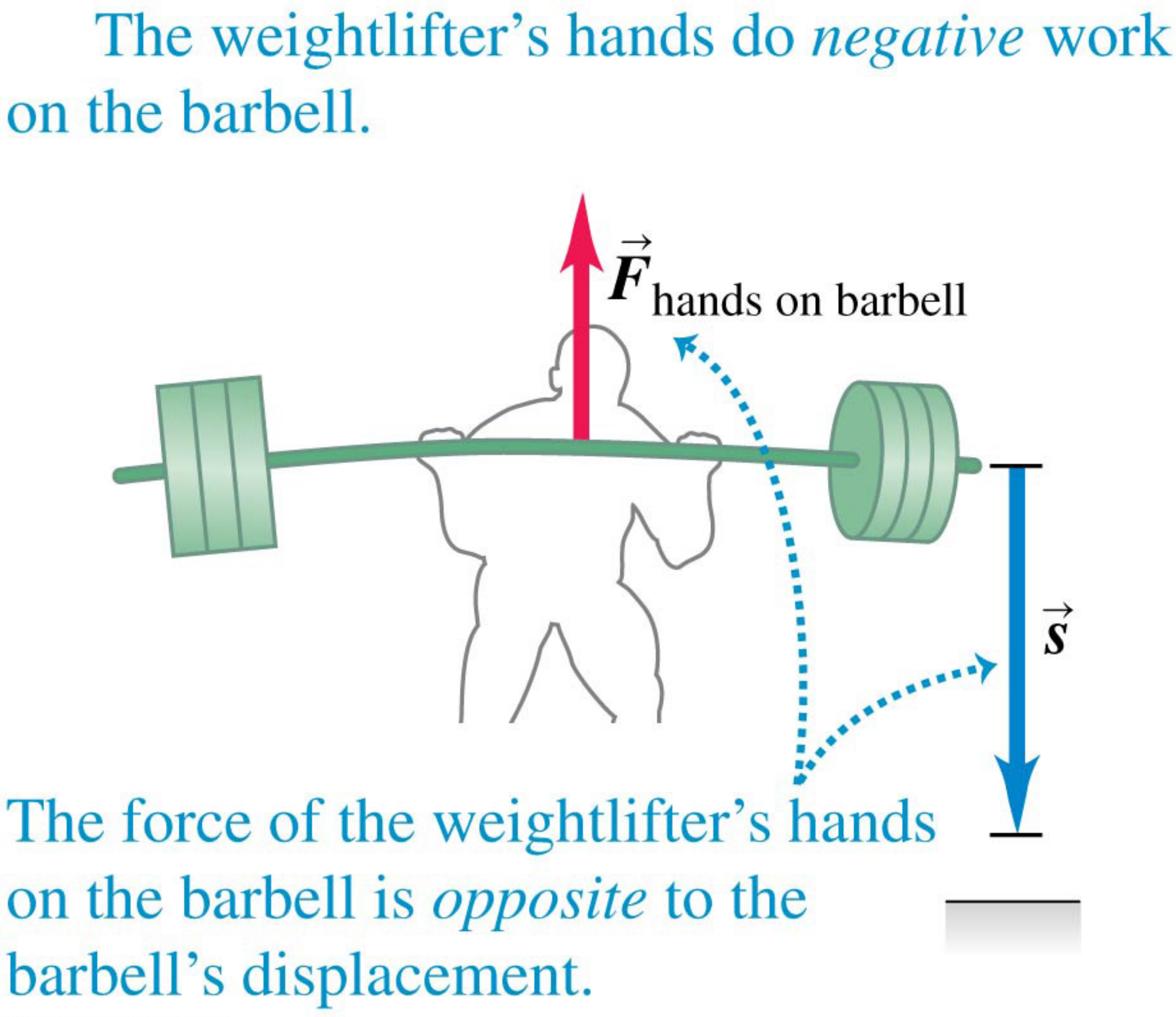
A weightlifter lowers a barbell to the floor.



Lowering the barbell to the floor: Slide 2

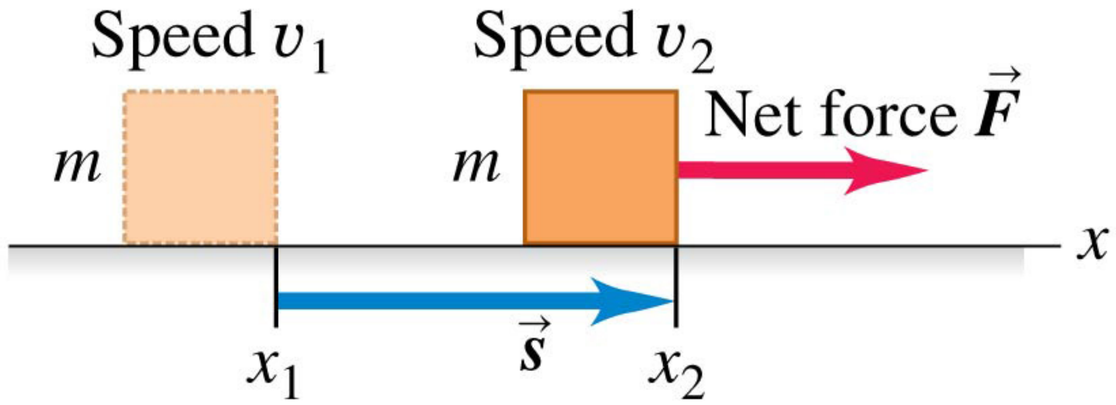


Lowering the barbell to the floor: Slide 3



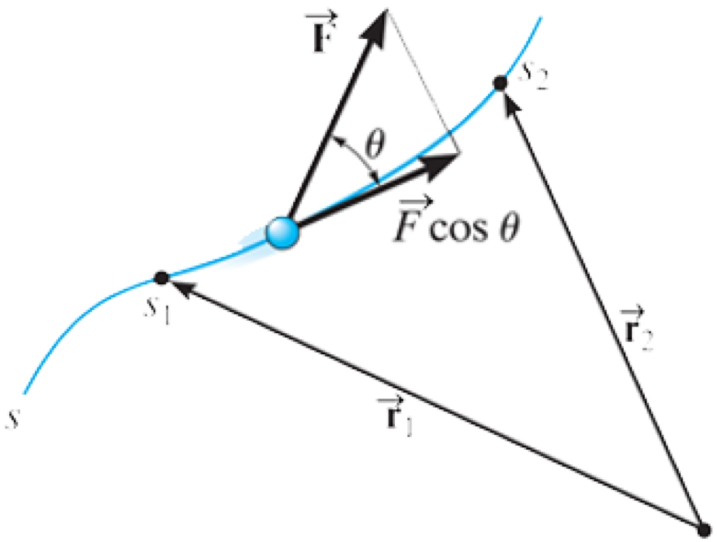
Total work

- The work done by the net force on a particle as it moves is called the **total work** W_{tot}.
- The particle speeds up if $W_{tot} > 0$, slows down if $W_{tot} < 0$, and maintains the same speed if $W_{tot} = 0$.



Work of a force: general formalism

A force does work on a particle when the particle undergoes a displacement along the line of action of the force.



Work is defined as the product of force and displacement components acting in the same direction. So, if the angle between the force and displacement vector is θ, the increment of work dW done by the force is

$$dW = F\, ds \cos\theta$$

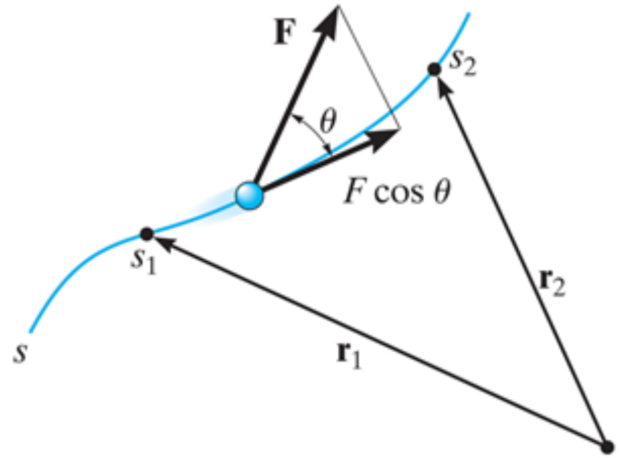
By using the definition of the dot product and integrating, the total work can be written as

$$W_{1\text{-}2} = \int_{\vec{r}_1}^{\vec{r}_2} \vec{F} \bullet d\vec{r}$$

Work of a force: general formalism

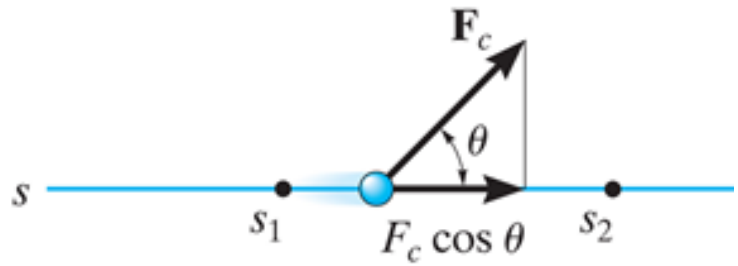
If $\boldsymbol{F}$ is a function of position (a common case) this becomes

$$W_{1\text{-}2} = \int_{s_1}^{s_2} \vec{F} \cos\theta \; ds$$



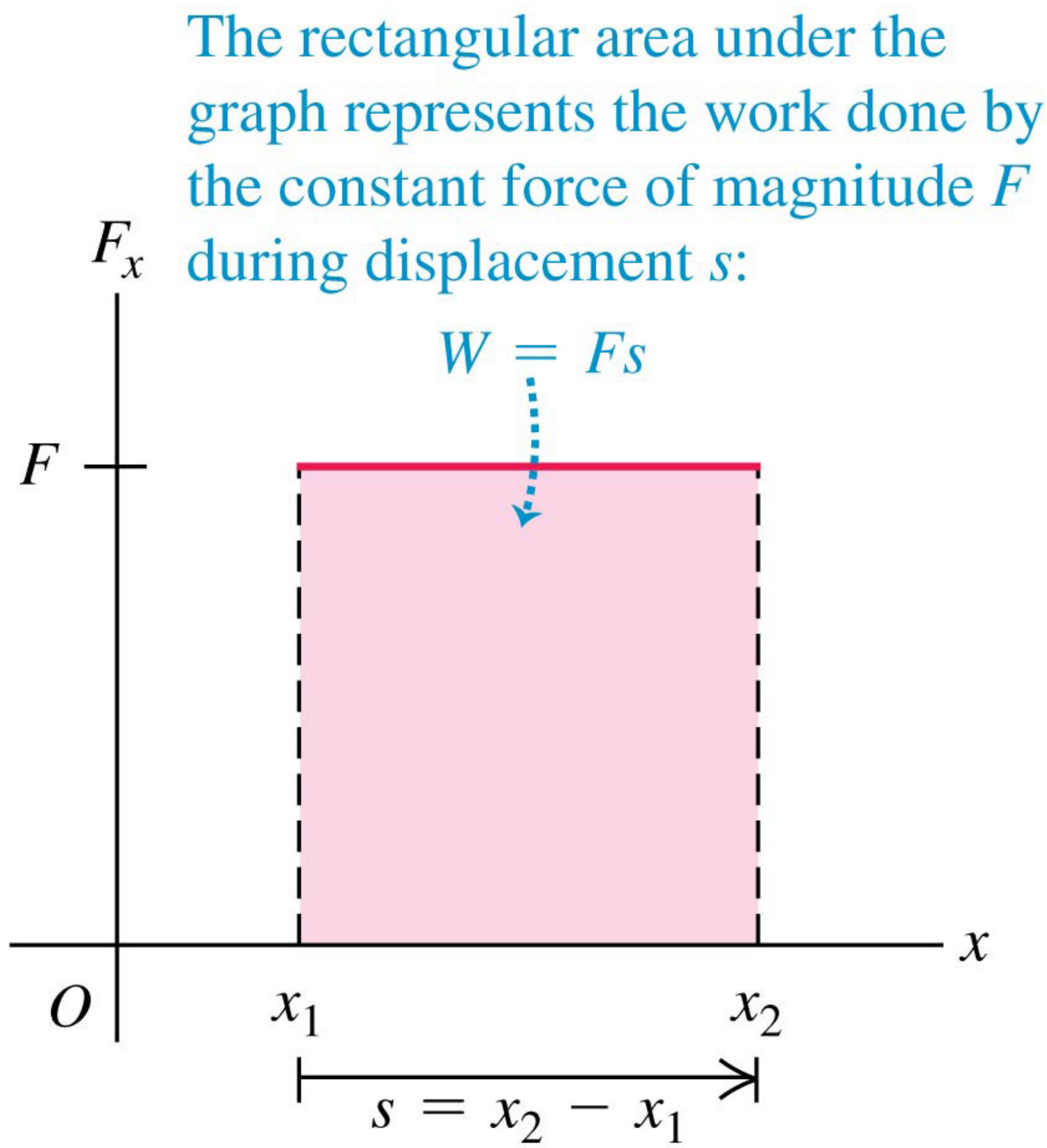
If both F and θ are constant ($F = F_c$), this equation further simplifies to

$$W_{1\text{-}2} = F_c \cos\theta \; (s_2 - s_1)$$



Work is positive if the force and the movement are in the same direction. If they are opposing, then the work is negative. If the force and the displacement directions are perpendicular, the work is zero.

Work done by a constant force

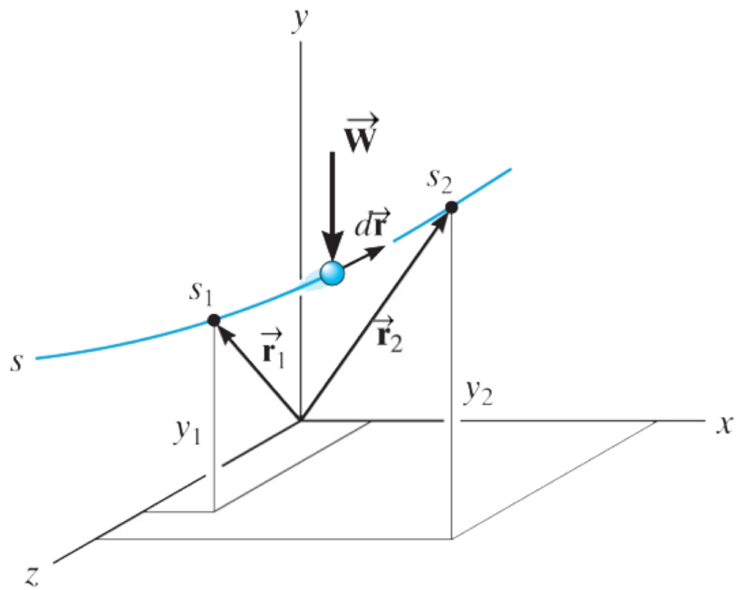


Work of a weight

The work done by the gravitational force acting on a particle (or weight of an object) can be calculated by using

$$W_{1\text{-}2} = \int_{y_1}^{y_2} -w\,dy$$

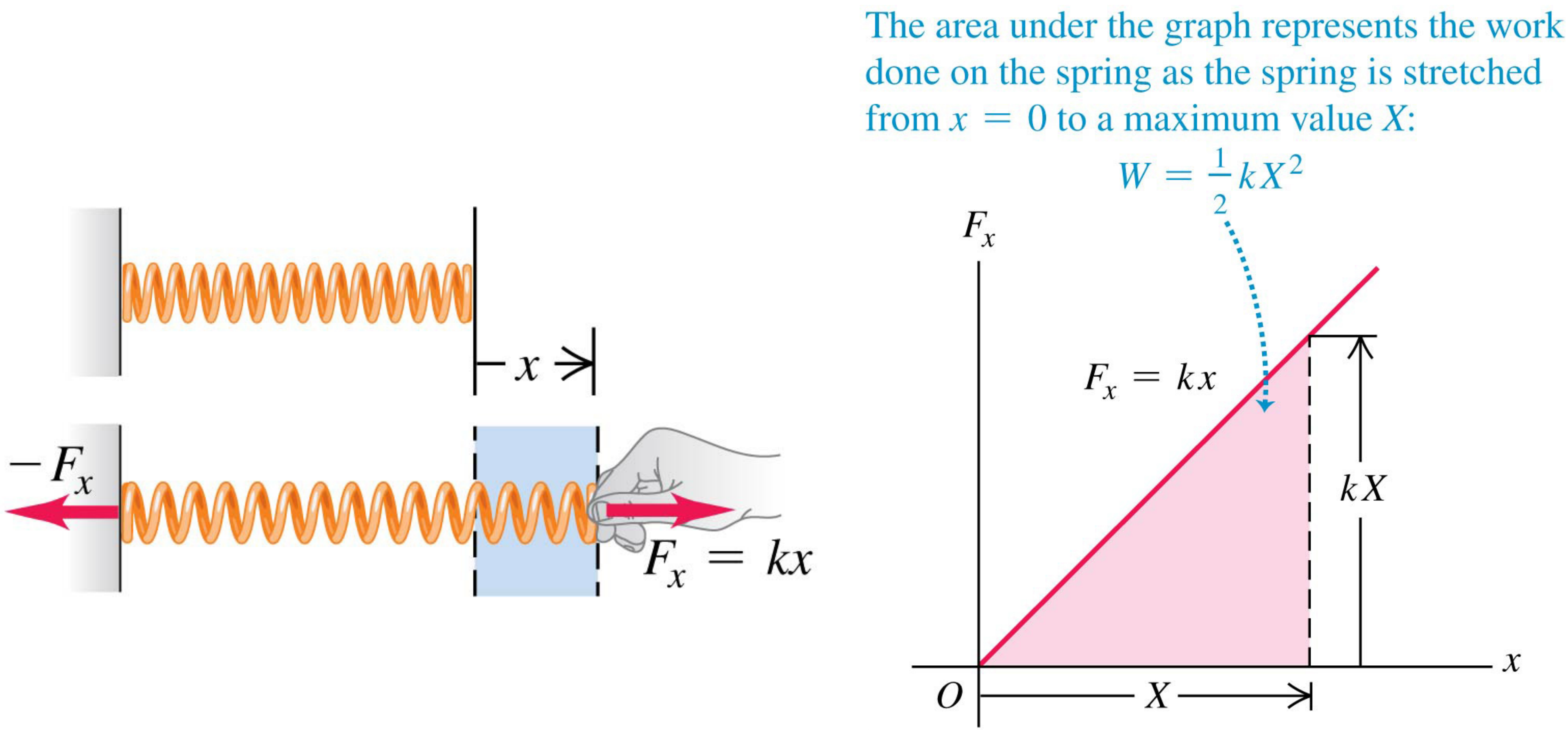
$$W_{1\text{-}2} = -w\,(y_2 - y_1) = -w\,\Delta y$$



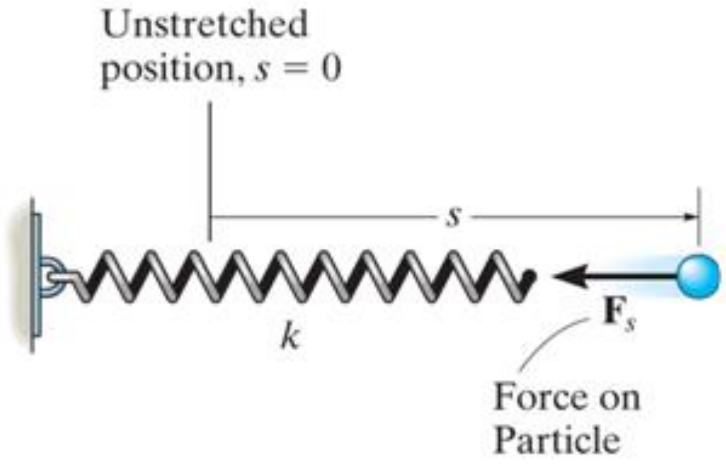
The work of a weight is the product of the magnitude of the particle's weight and its vertical displacement. If Δy is upward, the work is negative since the weight force always acts downward.

Stretching a spring

- The force required to stretch a spring a distance x is proportional to x: $F_x = kx$.
- The area under the graph represents the work done on the spring to stretch it a distance X: $W = 1/2\ kX^2$.



Work of a spring force



When stretched, a linear elastic spring develops a force of magnitude $F_s = ks$, where k is the spring stiffness and s is the displacement from the unstretched position.

The work of the spring force moving from position s_1 to position s_2 is

$$W_{1\text{-}2} = \int_{s_1}^{s_2} F_s \, ds = \int_{s_1}^{s_2} k\, s\, ds = 1/2\, k\, (s_2)^2 - 1/2\, k\, (s_1)^2$$

If a particle is attached to the spring, the force F_s exerted on the particle is opposite to that exerted on the spring. Thus, the work done on the particle by the spring force will be negative or

$$W_{1\text{-}2} = -[\, 1/2\, k\, (s_2)^2 - 1/2\, k\, (s_1)^2 \,] \;.$$

Spring forces

It is important to note the following about spring forces.

1. The equations above are for linear springs only! Recall that a linear spring develops a force according to $F = ks$ (essentially the equation of a line).

2. The work of a spring is not just spring force times distance at some point, i.e., $(ks_i)(s_i)$. Beware, this is a trap that students often fall into!

3. Always double-check the sign of the spring work after calculating it. It is positive work if the force on the object by the spring and the movement are in the same direction.

Kinetic energy

- The energy of motion of a particle is called **kinetic energy**:

Kinetic energy of a particle $\quad K = \frac{1}{2}mv^2 \quad$ Mass of particle; Speed of particle

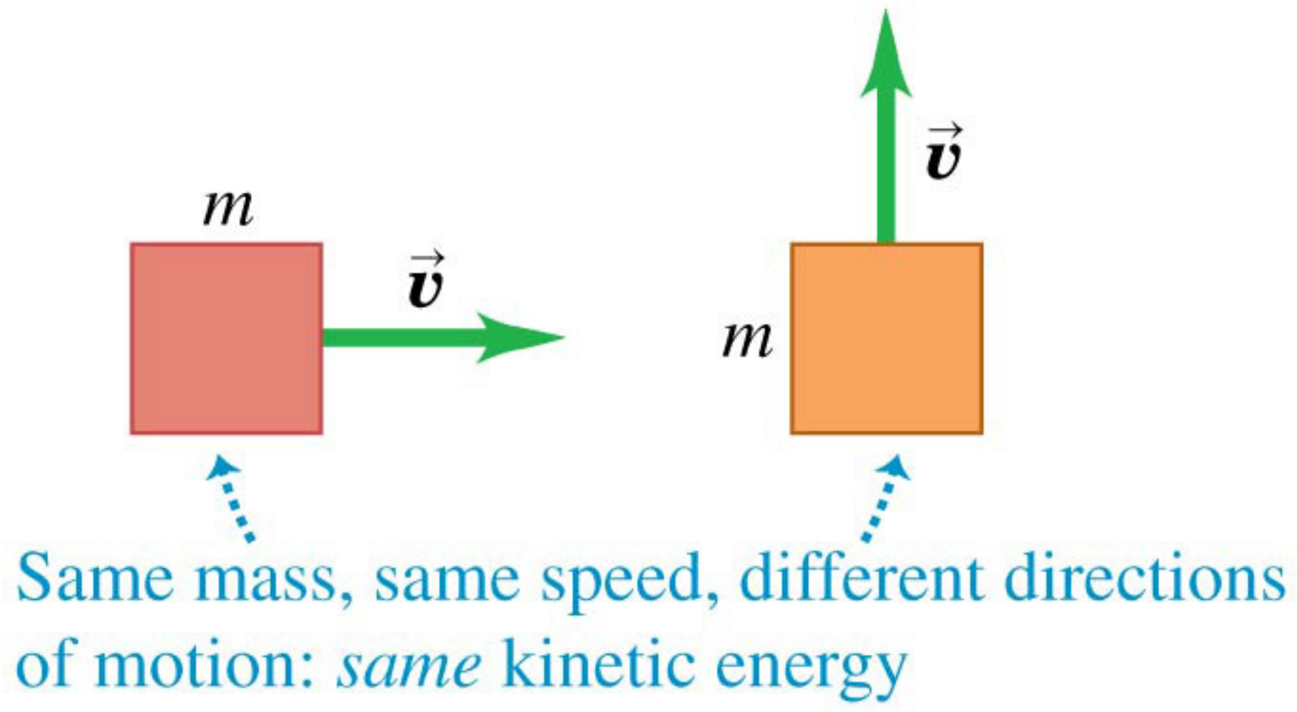
- Like work, the kinetic energy of a particle is a scalar quantity; it depends on only the particle's mass and speed, not its direction of motion.

- Kinetic energy can never be negative, and it is zero only when the particle is at rest.

- The SI unit of kinetic energy is the joule.

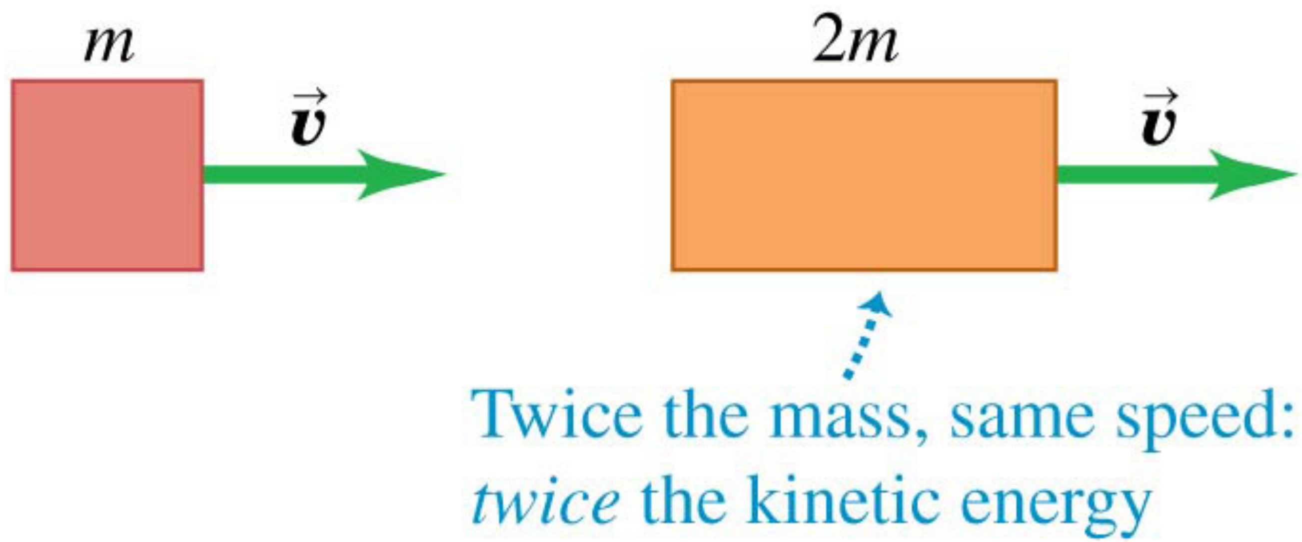
Kinetic energy

- Kinetic energy does not depend on the direction of motion.



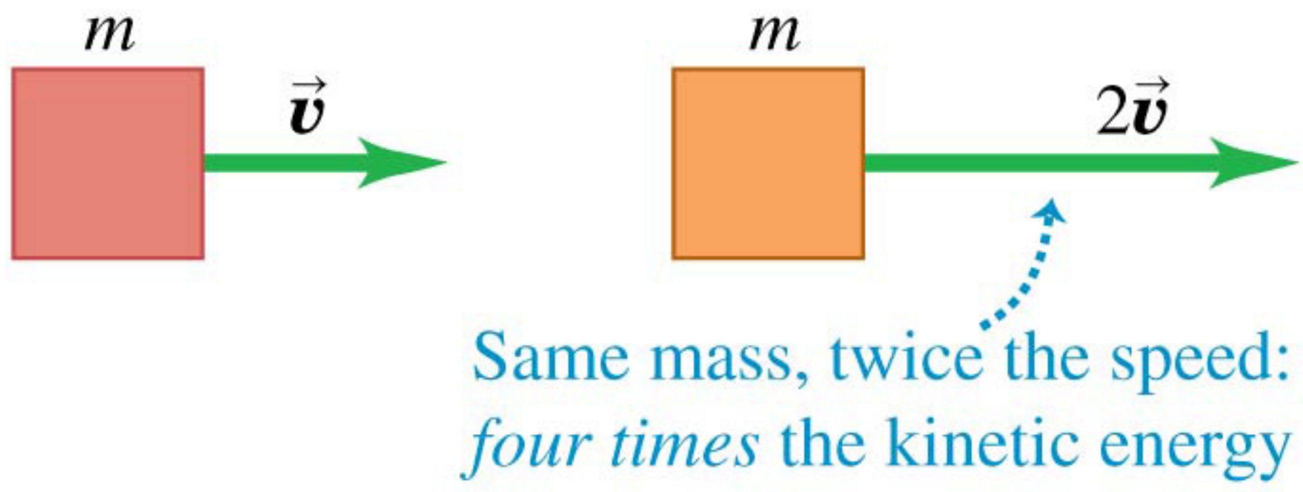
Kinetic energy

- Kinetic energy increases linearly with the mass of the object.



Kinetic energy

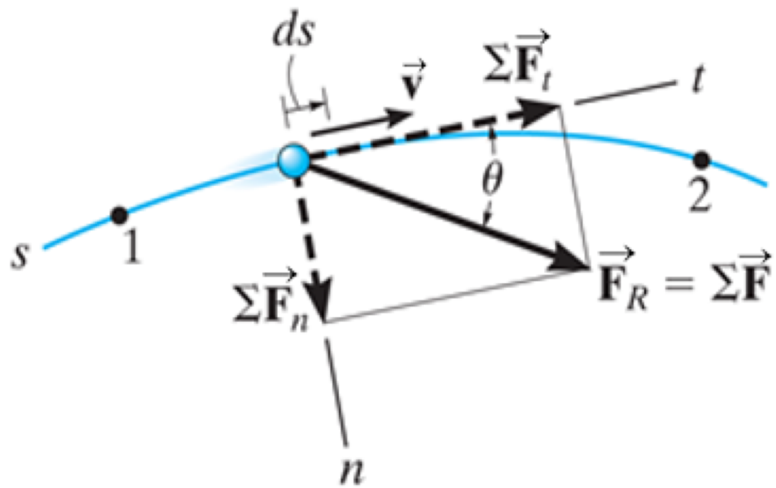
- Kinetic energy increases with the *square* of the speed of the object.



Work and energy

Another equation for working kinetics problems involving particles can be derived by integrating the equation of motion ($\boldsymbol{F}$ = m**a**) with respect to displacement.

By substituting $a_t = v(dv/ds)$ into $F_t = ma_t$, the result is integrated to yield an equation known as the principle of work and energy.



This principle is useful for solving problems that involve force, velocity, and displacement. It can also be used to explore the concept of power.

Principle of work and energy

By integrating the equation of motion, $\sum F_t = ma_t = mv(dv/ds)$, the principle of work and energy can be written as

$\sum W_{1\text{-}2} = 1/2\ m\ (v_2)^2 - 1/2\ m\ (v_1)^2$ or $K_1 + \sum W_{1\text{-}2} = K_2$

$\sum W_{1\text{-}2}$ is the work done by all the forces acting on the particle as it moves from point 1 to point 2. Work can be either a positive or negative scalar.

K_1 and K_2 are the kinetic energies of the particle at the initial and final position, respectively. Thus, $K_1 = 1/2\ m\ (v_1)^2$ and $K_2 = 1/2\ m\ (v_2)^2$. The kinetic energy is always a positive scalar (velocity is squared!).

So, the particle's initial kinetic energy plus the work done by all the forces acting on the particle as it moves from its initial to final position is equal to the particle's final kinetic energy.

Principle of work and energy

Note that the principle of work and energy $(K_1 + \sum W_{1\text{-}2} = K_2)$ is not a vector equation! Each term results in a scalar value.

Both kinetic energy and work have the same units, that of energy! In the SI system, the unit for energy is called a joule (J), where 1 J = 1 N·m. In the FPS system, units are ft·lb.

The principle of work and energy cannot be used, in general, to determine forces directed normal to the path, since these forces do no work.

The principle of work and energy can also be applied to a system of particles by summing the kinetic energies of all particles in the system and the work due to all forces acting on the system.

The work-energy theorem

- The **work-energy theorem**: The work done by the net force on a particle equals the change in the particle's kinetic energy.

Work–energy theorem: Work done by the net force on a particle equals the change in the particle's kinetic energy.

Total work done on particle = work done by net force

$$W_{tot} = K_2 - K_1 = \Delta K$$

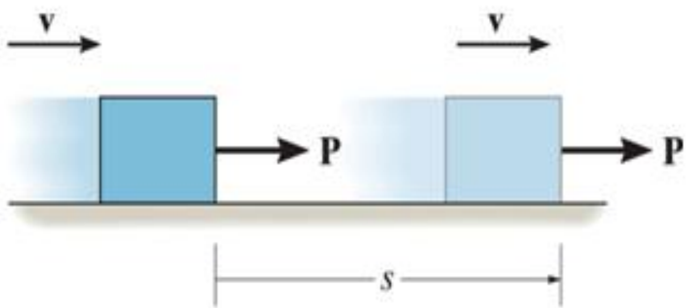
Change in kinetic energy

Final kinetic energy

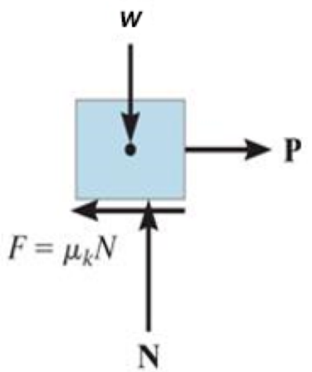
Initial kinetic energy

Work of friction caused by sliding

The case of a body sliding over a rough surface merits special consideration.



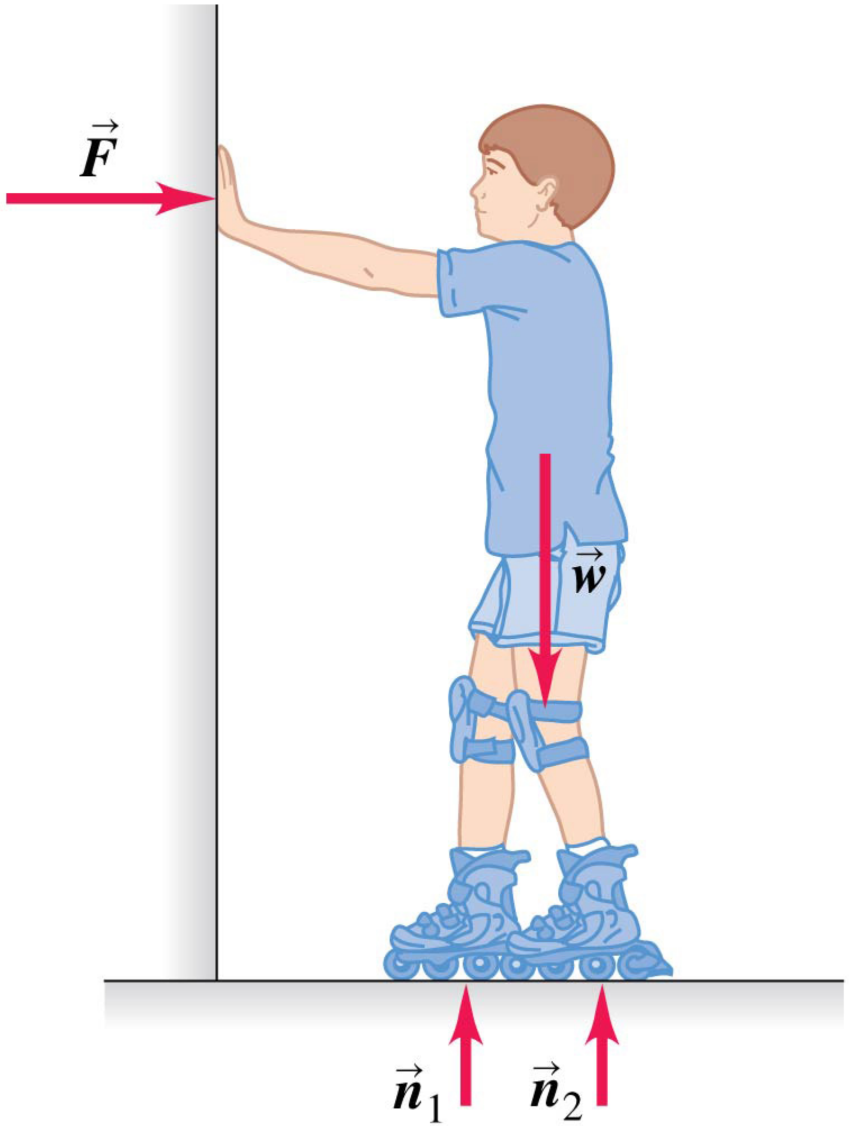
Consider a block which is moving over a rough surface. If the applied force ***P*** just balances the resultant frictional force $\mu_k N$, a constant velocity v would be maintained.



The principle of work and energy would be applied as
$0.5m\,(v)^2 + P\,s - (\mu_k N)\,s = 0.5m\,(v)^2$

This equation is satisfied if $P = \mu_k N$. However, we know from experience that friction generates heat, a form of energy that does not seem to be accounted for in this equation. It can be shown that the work term $(\mu_k N)s$ represents both the external work of the friction force and the internal work that is converted into heat.

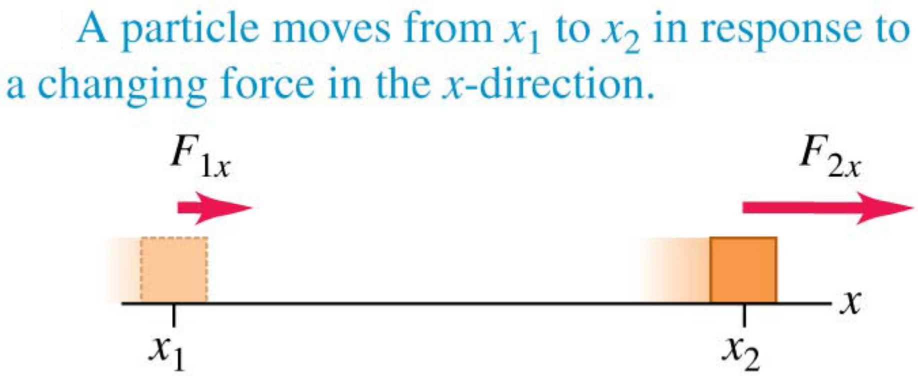
Work and kinetic energy in composite systems

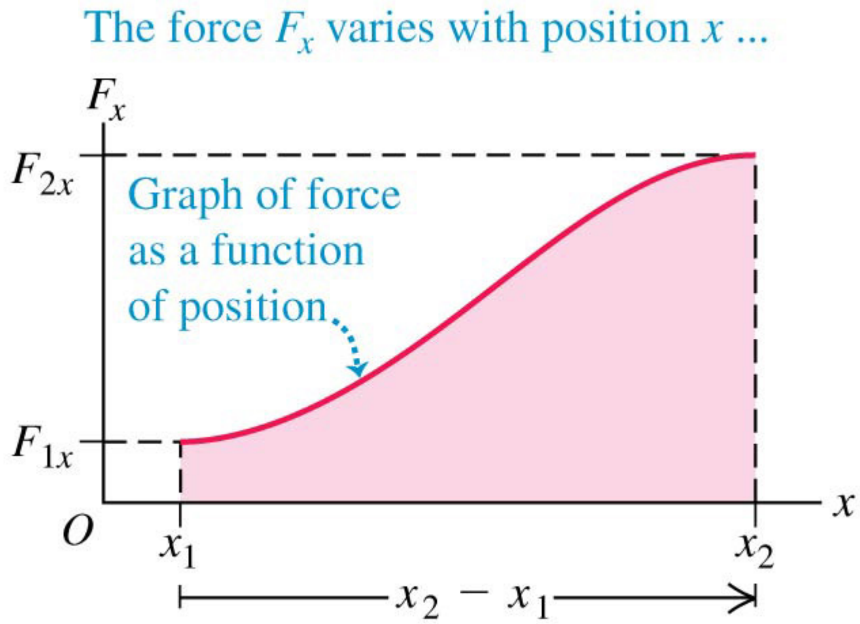


- The work done by the external forces acting on the skater is *zero*.
- But the skater's kinetic energy changes nonetheless!
- The explanation is that it's not adequate to represent the boy as a single point mass.

Work and energy with varying forces

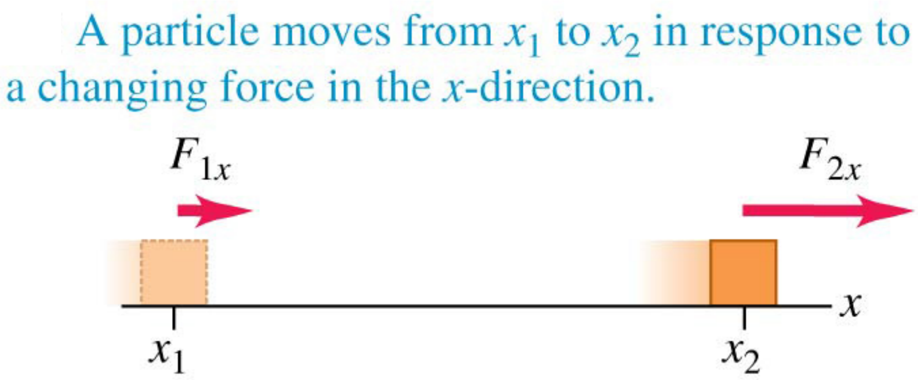
- Many forces are not constant.
- Suppose a particle moves along the x-axis from x_1 to x_2.

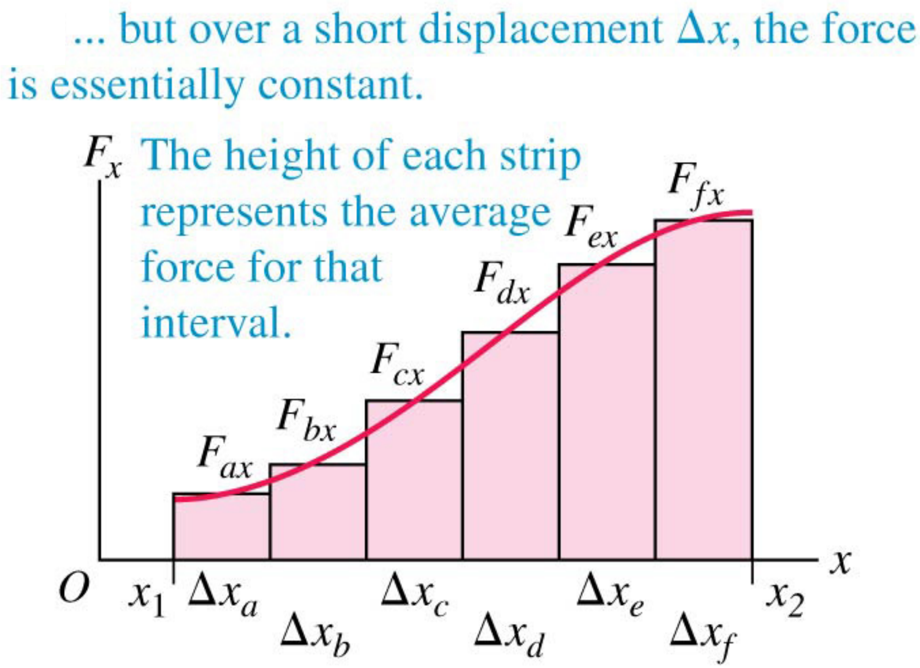




Work and energy with varying forces

- We calculate the approximate work done by the force over many segments of the path.
- We do this for each segment and then add the results for all the segments.





Work and energy with varying forces

- The work done by the force in the total displacement from x_1 to x_2 is the integral of F_x from x_1 to x_2:

Work done on a particle by a **varying x-component of force F_x** during **straight-line displacement** along x-axis

$$W = \int_{x_1}^{x_2} F_x \, dx$$

Upper limit = final position

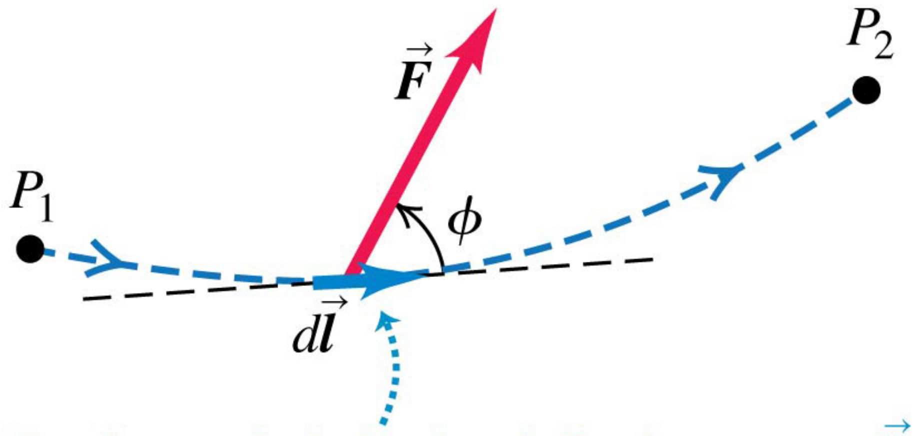
Integral of x-component of force

Lower limit = initial position

- On a graph of force as a function of position, the total work done by the force is represented by the *area* under the curve between the initial and final positions.

Work–energy theorem for motion along a curve

- A particle moves along a curved path from point P_1 to P_2, acted on by a force that varies in magnitude and direction.
- The work can be found using a *line integral*:



During an infinitesimal displacement $d\vec{l}$, the force $\vec{F}$ does work dW on the particle:

$$dW = \vec{F} \cdot d\vec{l} = F \cos\phi \, dl$$

Upper limit = final position

Scalar product (dot product) of $\vec{F}$ and displacement $d\vec{l}$

$$W = \int_{P_1}^{P_2} \vec{F} \cdot d\vec{l} = \int_{P_1}^{P_2} F \cos\phi \, dl = \int_{P_1}^{P_2} F_{\parallel} \, dl$$

Work done on a particle by a **varying force** $\vec{F}$ along a **curved path**

Lower limit = initial position

Angle between $\vec{F}$ and $d\vec{l}$

Component of $\vec{F}$ parallel to $d\vec{l}$

Quiz

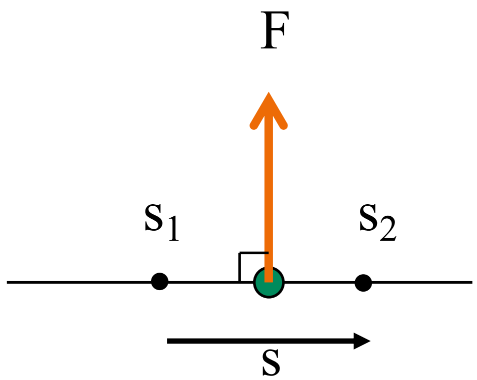
1. What is the work done by the force F?

A) F s

B) –F s

C) Zero

D) None of the above.



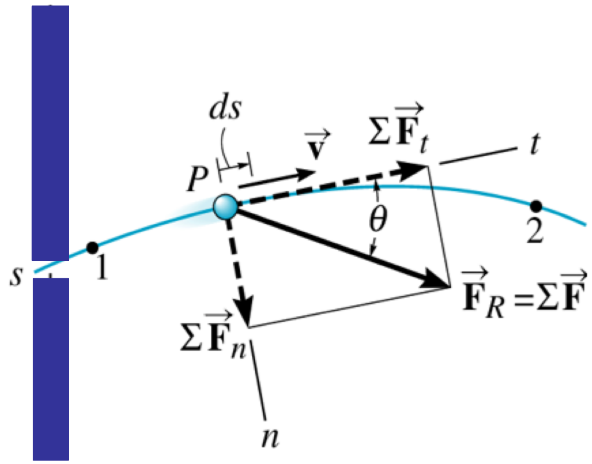
2. If a particle is moved from 1 to 2, the work done on the particle by the force, F_R will be

A) $\int_{s_1}^{s_2} \sum F_t ds$

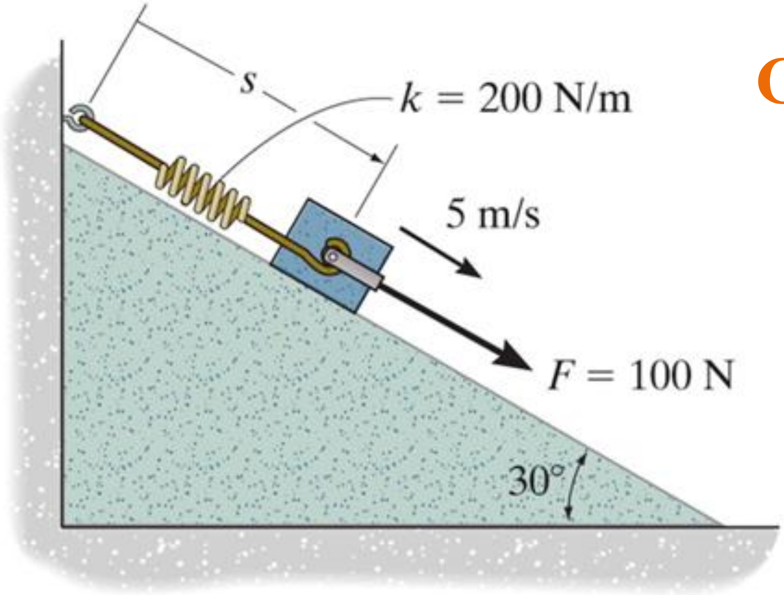
B) $-\int_{s_1}^{s_2} \sum F_t ds$

C) $-\int_{s_1}^{s_2} \sum F_n ds$

D) $\int_{s_1}^{s_2} \sum F_n ds$



Example



Given: When s = 0.6 m, the spring is not stretched or compressed, and the 10-kg block, which is subjected to a force of 100 N, has a speed of 5 m/s down the smooth plane.

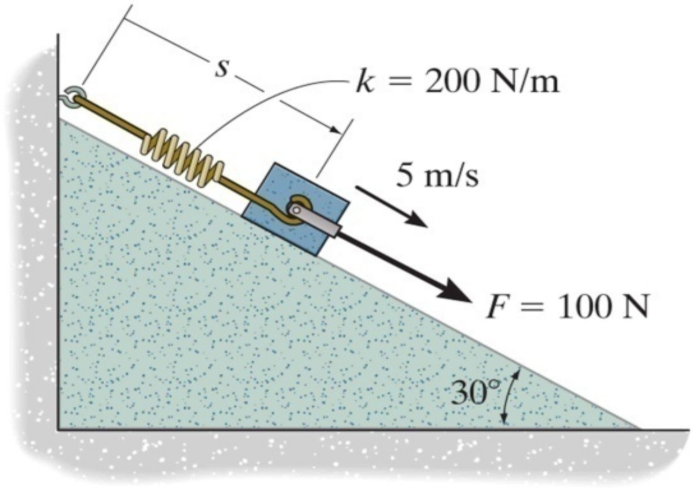
Find: The distance s when the block stops.

Plan: Since this problem involves forces, velocity and displacement, apply the principle of work and energy to determine s.

Example

Solution:

Apply the principle of work and energy between position 1 (s_1 = 0.6 m) and position 2 (s_2). Note that the normal force (***N***) does no work since it is always perpendicular to the displacement.



$$K_1 + \sum W_{1\text{-}2} = K_2$$

There is work done by three different forces:

1) work of a the force F =100 N;

$$W_F = 100\ (s_2 - s_1) = 100\ (s_2 - 0.6)$$

2) work of the block weight;

$$W_w = 10\ (9.81)\ (s_2 - s_1) \sin 30° = 49.05\ (s_2 - 0.6)$$

3) and, work of the spring force.

$$W_S = -\ 0.5\ (200)\ (s_2 - 0.6)^2 = -100\ (s_2 - 0.6)^2$$

Example

The work and energy equation will be

$K_1 + \sum W_{1\text{-}2} = K_2$

$$0.5\,(10)\,5^2 + 100(s_2 - 0.6) + 49.05(s_2 - 0.6) - 100(s_2 - 0.6)^2 = 0$$

$$\Rightarrow\; 125 + 149.05(s_2 - 0.6) - 100(s_2 - 0.6)^2 = 0$$

Solving for $(s_2 - 0.6)$,

$$(s_2 - 0.6) = \{-149.05 \pm (149.05^2 - 4\times(-100)\times 125)^{0.5}\} \,/\, 2(-100)$$

Selecting the positive root, indicating a positive spring deflection,

$$(s_2 - 0.6) = 2.09 \text{ m}$$

Therefore, $s_2 = 2.69$ m

Quiz

1. A spring with an unstretched length of 50 mm expands from a length of 20 mm to a length of 40 mm. The work done on the spring is __________ N·mm.

   A) $-[0.5\ k(40\ \text{mm})^2 - 0.5\ k(20\ \text{mm})^2]$

   B) $0.5\ k\ (20\ \text{mm})^2$

   ✔C) $-[0.5\ k(30\ \text{mm})^2 - 0.5\ k(10\ \text{mm})^2]$

   D) $0.5\ k(30\ \text{mm})^2 - 0.5\ k(0\ \text{mm})^2$

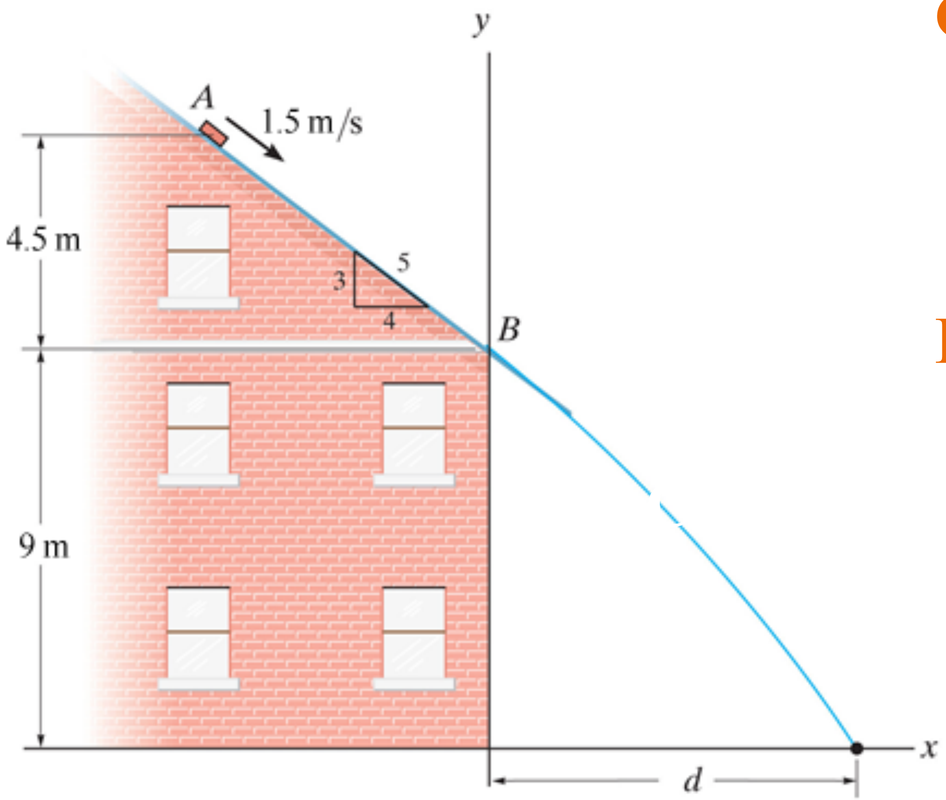
2. If a spring force is $F = 5\ s^3$ N/m and the spring is compressed by $s = 0.5$ m, the work done on a particle attached to the spring will be

   A) $0.625\ \text{N} \cdot \text{m}$ B) $-0.625\ \text{N} \cdot \text{m}$

   C) $0.0781\ \text{N} \cdot \text{m}$ ✔D) $-0.0781\ \text{N} \cdot \text{m}$

5/4 (0.5)^4

Example



Given: The 1-kg brick slides down a smooth roof, with v_A=1.5 m/s.

Find: The speed at B, the distance d from the wall to where the brick strikes the ground, and its speed at C.

Plan:

1) Apply the principle of work and energy to the brick, and determine the speeds at B and C.
2) Apply the kinematic relations in x and y-directions.

Example

Solution:

1) Apply the principle of work and energy

$$\Sigma \mathrm{K_A} + \Sigma \mathrm{U_{A-B}} = \Sigma \mathrm{K_B}$$

$$\frac{1}{2}(1)\ (1.5)^2 + (1)(9.81)(4.5) = \frac{1}{2}\ (1)(\mathrm{v}_B)^2$$

Solving for the unknown velocity yields $\mathrm{v_B} = 9.515$ m/s

Similarly, apply the work and energy principle between A and C

$$\Sigma \mathrm{K_A} + \Sigma \mathrm{U_{A-C}} = \Sigma \mathrm{K_C}$$

$$\frac{1}{2}(1)\ (1.5)^2+(1)(9.81)(13.5) = \frac{1}{2}\ (1)(\mathrm{v}_C)^2$$

$\mathrm{v_C} = 16.34$ m/s

Example

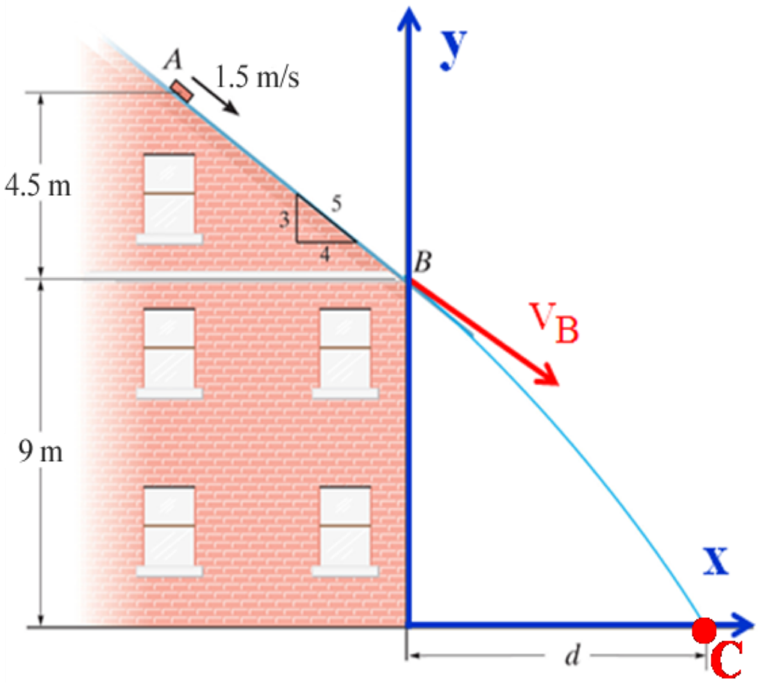
2) Apply the kinematic relations in x and y-directions:

Equation for horizontal motion

$(+\rightarrow)\quad x_C = x_B + v_{Bx}\, t_{BC}$

$d = 0 + 9.515\,(4/5)\, t_{BC}$

$\Rightarrow d = 7.612\, t_{BC}$



Equation for vertical motion

$(+\uparrow)\ y_C = y_B + v_{By}\, t_{BC} - 0.5\, g\, t_{BC}^2$

$\Rightarrow\quad -9 = 0 + (-9.515)(3/5)\, t_{BC} - 0.5\,(9.81)\, t_{BC}^2$

Solving for the positive t_{BC} yields $t_{BC} = 0.8923$ s.

$\Rightarrow d = 7.612\, t_{BC} = 7.612\,(0.8923) = 6.79$ m

Quiz

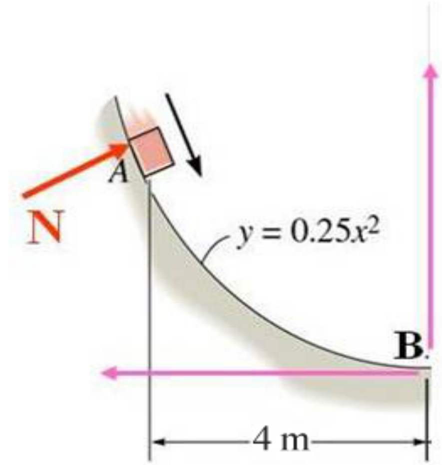
What is the work done by the normal force N if a 2-kg box is moved from A to B ?

A)- 78.5 N · m

B) 0 N · m

C) 78.5 N · m

D) 157 N · m



Power

- **Power** is the *rate* at which work is done.

- **Average power** is:

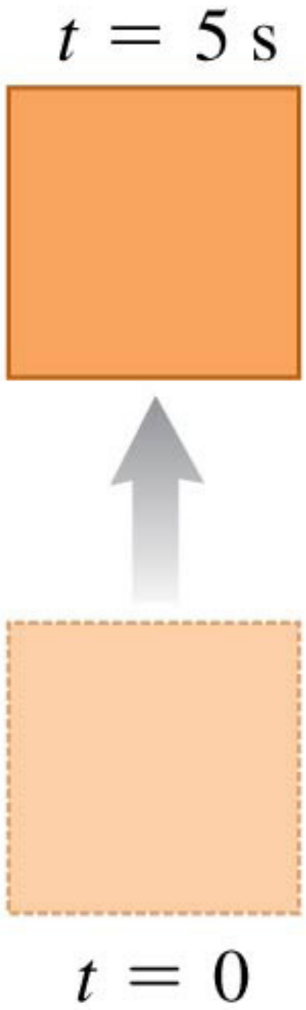
$$\underbrace{P_{av}}_{\text{Average power during time interval } \Delta t} = \frac{\overbrace{\Delta W}^{\text{Work done during time interval}}}{\underbrace{\Delta t}_{\text{Duration of time interval}}}$$

- **Instantaneous power** is:

$$\underbrace{P}_{\text{Instantaneous power}} = \underbrace{\lim_{\Delta t \to 0} \frac{\Delta W}{\Delta t}}_{\text{Average power over infinitesimally short time interval}} = \underbrace{\frac{dW}{dt}}_{\text{Time rate of doing work}}$$

- The SI unit of power is the **watt** (1 W = 1 J/s), but another familiar unit is the *horsepower* (1 hp = 746 W).

Power: Lifting a box slowly



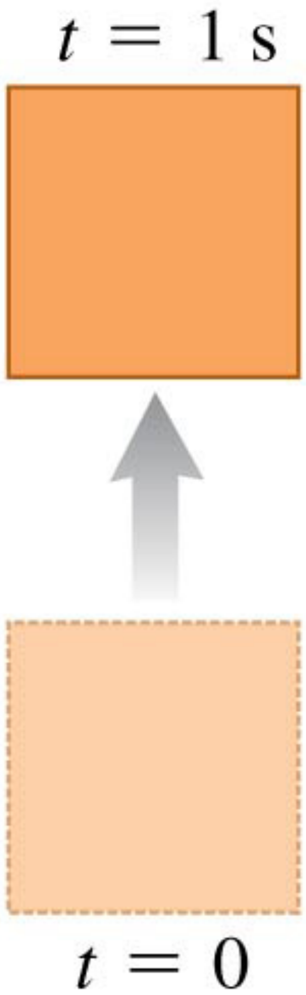
Work you do on the box
to lift it in 5 s:

$$W = 100\ \text{J}$$

Your power output:

$$P = \frac{W}{t} = \frac{100\ \text{J}}{5\ \text{s}} = 20\ \text{W}$$

Power: Lifting a box quickly



Work you do on the same box to lift it the same distance in 1 s:

$$W = 100 \text{ J}$$

Your power output:

$$P = \frac{W}{t} = \frac{100 \text{ J}}{1 \text{ s}} = 100 \text{ W}$$

Power

- In mechanics we can also express power in terms of force and velocity:

Instantaneous power for a force doing work on a particle

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

Force that acts on particle

Velocity of particle

- Here is a one-horsepower (746-W) propulsion system.

Power: general formalism

Power is defined as the amount of work performed per unit of time.

If a machine or engine performs a certain amount of work, dW, within a given time interval, dt, the power generated can be calculated as

$$P = dW/dt$$

Since the work can be expressed as $dW = \vec{F} \cdot d\vec{x}$, the power can be written

$$P = dW/dt = (\vec{F} \cdot d\vec{x})/dt = \vec{F} \cdot (d\vec{x}/dt) = \vec{F} \cdot \vec{v}$$

Thus, power is a scalar defined as the product of the force and velocity components acting in the same direction.

Power

Using scalar notation, power can be written

$P = \vec{F} \bullet \vec{v} = F\, v \cos \theta$

where θ is the angle between the force and velocity vectors.

So if the velocity of a body acted on by a force $\vec{F}$ is known, the power can be determined by calculating the dot product or by multiplying force and velocity components.

The unit of power in the SI system is the Watt (W) where

$1\ W = 1\ J/s = 1\ (N \cdot m)/s.$

Efficiency

The mechanical efficiency of a machine is the ratio of the useful power produced (output power) to the power supplied to the machine (input power) or
ε = (power output) / (power input)

If energy input and removal occur at the same time, efficiency may also be expressed in terms of the ratio of output energy to input energy or
ε = (energy output) / (energy input)

Machines will always have frictional forces. Since frictional forces dissipate energy, additional power will be required to overcome these forces. Consequently, the efficiency of a machine is always less than 1.

Procedure for analysis

- Find the resultant external force acting on the body causing its motion. It may be necessary to draw a free-body diagram.
- Determine the velocity of the point on the body at which the force is applied. Energy methods or the equation of motion and appropriate kinematic relations, may be necessary.
- Multiply the force magnitude by the component of velocity acting in the direction of $\vec{F}$ to determine the power supplied to the body ($P = F\, v \cos\,\theta$).
- In some cases, power may be found by calculating the work done per unit of time ($P = dW/dt$).
- If the mechanical efficiency of a machine is known, either the power input or output can be determined.

Quiz

1. The formula definition of power is ____________.

   A) dW / dt B) $\vec{F} \bullet \vec{v}$

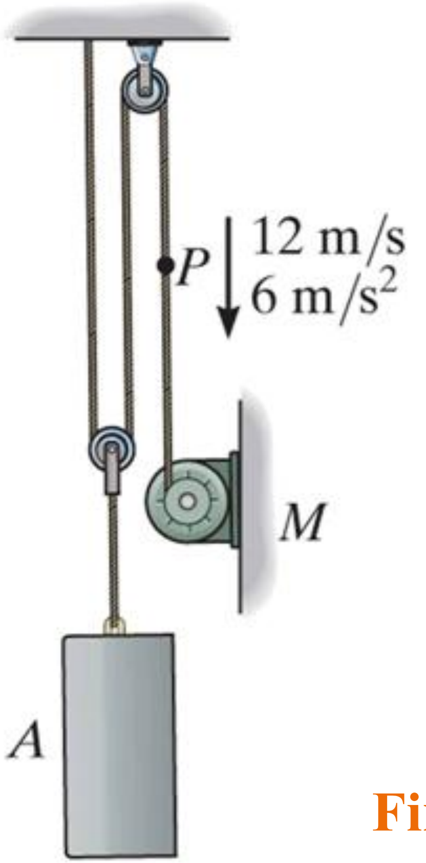
   C) $\vec{F} \bullet d\vec{x}/dt$ ✔ D) All of the above.

2. Kinetic energy results from ________.

   A) displacement ✔ B) velocity

   C) gravity D) friction

Example



Given: A 50-kg block (A) is hoisted by the pulley system and motor M. The motor has an efficiency of 0.8. At this instant, point P on the cable has a velocity of 12 m/s which is increasing at a rate of 6 m/s^2. Neglect the mass of the pulleys and cable.

Find: The power supplied to the motor at this instant.

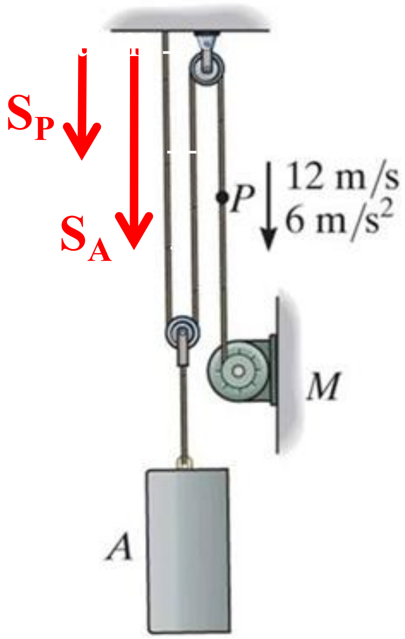
Plan:

1) Relate the cable and block velocities by defining position coordinates. Draw a FBD of the block.
2) Use the equation of motion to determine the cable tension.
3) Calculate the power supplied by the motor and then to the motor.

Example

Solution:

1) Define position coordinates to relate velocities.



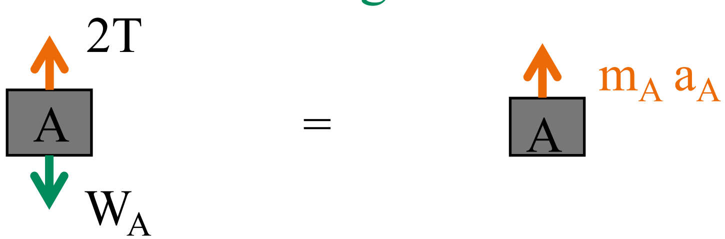
Here s_P is defined to a point on the cable. Also s_A is defined only to the lower pulley, since the block moves with the pulley. From kinematics,

$$s_P + 2\, s_A = l$$

$$\Rightarrow \quad a_P + 2\, a_A = 0$$

$$\Rightarrow \quad a_A = -\, a_P / 2 = -3 \text{ m/s}^2 \,(\uparrow)$$

Draw the FBD and kinetic diagram of the block:



Example

2) The tension of the cable can be obtained by applying the equation of motion to the block.

$$+\uparrow \ \sum F_y = m_A \, a_A$$

$$2T - 490.5 = 50\,(3) \ \Rightarrow \ T = 320.3 \text{ N}$$

3) The power supplied by the motor is the product of the force applied to the cable and the velocity of the cable.

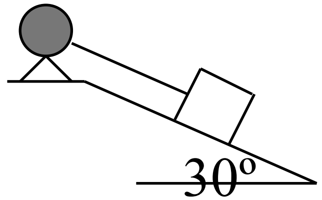
$$P_o = \vec{F} \bullet \vec{v} = (320.3)(12) = 3844 \text{ W}$$

The power supplied to the motor is determined using the motor's efficiency and the basic efficiency equation.

$$P_i = P_o/e = 3844/0.8 = 4804 \text{ W} = 4.8 \text{ kW}$$

Quiz

1. A motor pulls a 10-kg block up a smooth incline at a constant velocity of 4 m/s. Find the power supplied by the motor.



✔ A) 196.2 watts B) 339.8 watts
C) 392.4 watts D) 40 watts

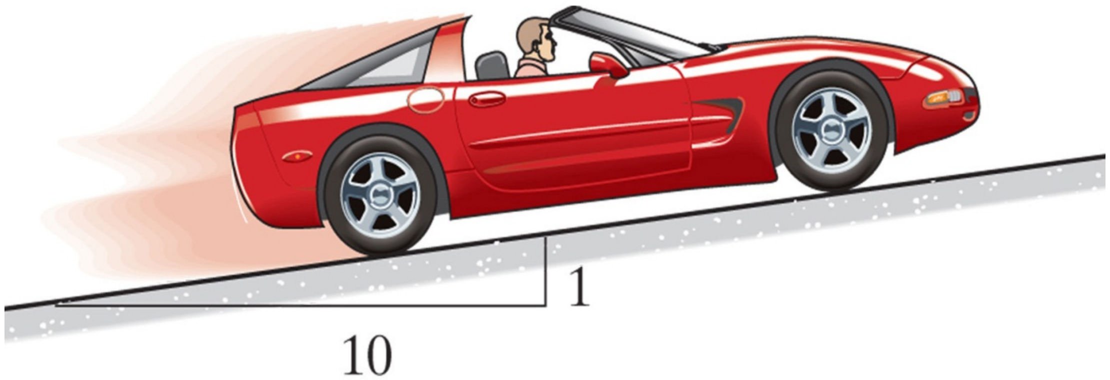
(10*9.81*0.5)*4

2. A twin engine jet aircraft is climbing at a 10 degree angle at 78 m/s. The thrust developed by a jet engine is 5000 N. The power developed by the aircraft is

A) (5000 N)(78 m/s) B) (10000 N)(78 m/s) cos 10°

C) (5000 N)(78 m/s) cos 10° ✔ D) (10000 N)(78 m/s)

Example



Given: A 2000-kg sports car increases its speed uniformly from rest to 25 m/s in 30 s. The engine efficiency $\varepsilon = 0.8$.

Find: The maximum power and the average power supplied by the engine.

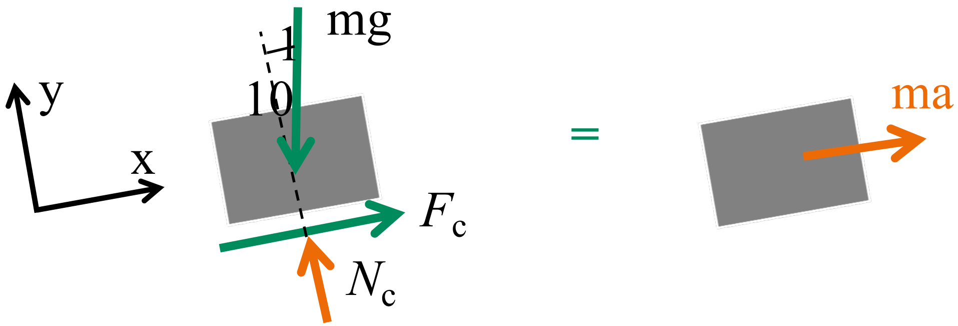
Plan:

1) Draw the car's free-body and kinetic diagrams.
2) Apply the equation of motion and kinematic equations to find the force.
3) Determine the output power required.
4) Use the engine's efficiency to determine input power.

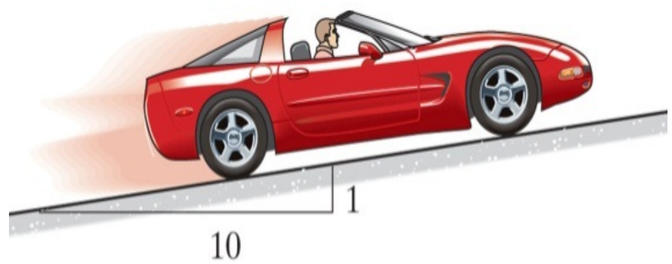
Example

Solution:

1) Draw the FBD & Kinetic Diagram of the car as a particle.



The normal force $\vec{N}_c$ and frictional force $\vec{F}_c$ represent the resultant forces of all four wheels.



The frictional force between the wheels and road pushes the car forward. What are we neglecting with this approach?

Example

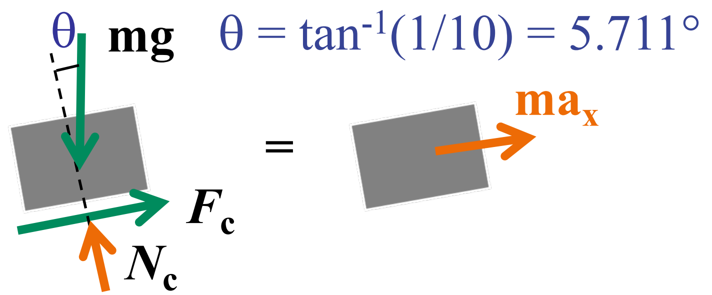
2) The equation of motion

$\xrightarrow{+}$ $\sum F_x = ma_x \Rightarrow -2000\,g\,(\sin 5.711°) + F_c = 2000\,a_x$

Determine a_x using constant acceleration equation

$\Rightarrow v = v_0 + a_x\,t$

$a_x = (25 - 0) / 30 = 8.333 \text{ m/s}^2$



Substitute a_x into the equation of motion and determine frictional force F_c :

$F_c = 2000\,a_x + 2000\,g\,(\sin 5.711°)$

$= 2000(8.333) + 2000\,(9.81)\,(\sin 5.711) = 3619 \text{ N}$

Example

3) The max power output of the car is calculated by multiplying the driving (frictional) force and the car's final speed:

$$(P_{out})_{max} = (F_c)(v_{max}) = 3619\ (25) = 90.47\ \text{kW}$$

The average power output is the force times the car's average speed:

$$(P_{out})_{avg} = (F_c)(v_{avg}) = 3619\ (25/2) = 45.28\ \text{kW}$$

4) The power supplied by the engine is obtained using the efficiency equation.

$$(P_{in})_{max} = (P_{out})_{max} / \varepsilon = 90.47 / 0.8 = 113\ \text{kW}$$

$$(P_{in})_{avg} = (P_{out})_{avg} / \varepsilon = 45.28 / 0.8 = 56.5\ \text{kW}$$

Quiz

1. The power supplied by a machine will always be __________ the power supplied to the machine.

   ✔ A) less than B) equal to

   C) greater than D) A or B

2. A car is traveling a level road at 25 m/s. The power being supplied to the wheels is 80000 W. Find the combined friction force on the tires.

   A) 863 N B) 2500 N

   ✔ C) 3200 N D) 2.0×10^6 N