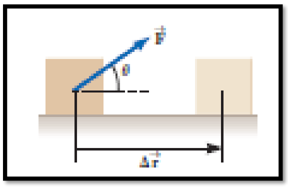
Energy and energy transfer

7.2 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 $\cos\theta$, where θ is the angle between the force and displacement vectors:

$$W = \vec{F} \cdot \Delta\vec{r} = F\Delta r cos\theta \ (1)$$

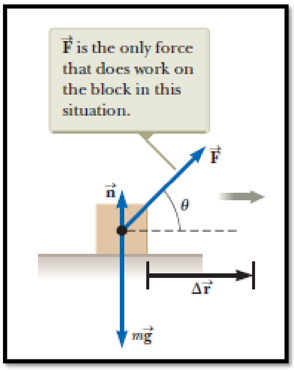


7.2 Work Done by a Constant Force:

The units of work are those of force multiplied by those of length. Therefore, the SI unit of work is the **newton·meter**

$$(J = N \cdot m = kg \cdot m^2/s^2)$$

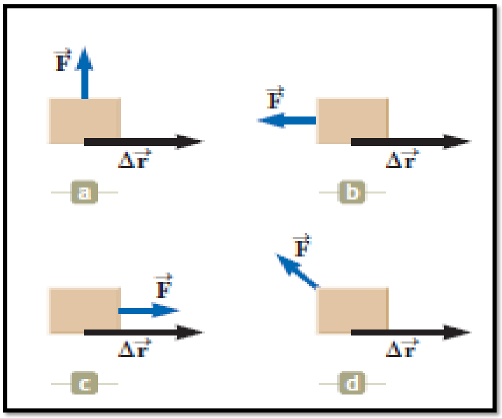
This combination of units is used so frequently that it has been given a name of its own, the **joule** (J).



- **work is an energy transfer.**
- If W is the work done on a system and W is positive, energy is transferred *to* the system
- if W is negative, energy is transferred *from* the system.

7.2 Work Done by a Constant Force:

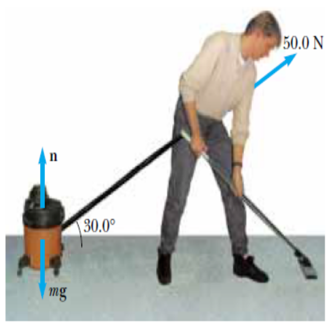
Quiz: A force is applied to an object. In all four cases, the force has the same magnitude, and the displacement of the object is to the right and of the same magnitude.
Rank the work done by the force on the object, from most positive to most negative.



7.2 Work Done by a Constant Force:

Example 7.1 Mr. Clean

A man cleaning a floor pulls a vacuum cleaner with a force of magnitude $F = 50.0$ N at an angle of 30.0° with the horizontal (Fig. 7.5a). Calculate the work done by the force on the vacuum cleaner as the vacuum cleaner is displaced 3.00 m to the right.



7.3 The Scalar Product of Two Vectors

Example 7.2 The Scalar Product

The vectors **A** and **B** are given by $\mathbf{A} = 2\hat{\mathbf{i}} + 3\hat{\mathbf{j}}$ and $\mathbf{B} = -\hat{\mathbf{i}} + 2\hat{\mathbf{j}}$.

(A) Determine the scalar product $\mathbf{A} \cdot \mathbf{B}$.

(B) Find the angle θ between **A** and **B**.

7.3 The Scalar Product of Two Vectors

Example 7.3 Work Done by a Constant Force

A particle moving in the xy plane undergoes a displacement $\Delta\mathbf{r} = (2.0\hat{\mathbf{i}} + 3.0\hat{\mathbf{j}})$ m as a constant force $\mathbf{F} = (5.0\hat{\mathbf{i}} + 2.0\hat{\mathbf{j}})$ N acts on the particle.

(A) Calculate the magnitudes of the displacement and the force.

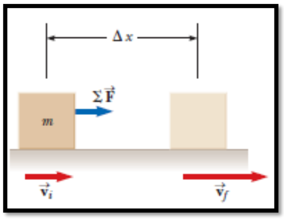
(B) Calculate the work done by $\mathbf{F}$.

7.4 Work Done by a Varying Force

Consider a system consisting of a single object. Figure shows a block of mass m moving through a displacement directed to the right under the action of a net force $\sum \vec{F}$, also directed to the right. We know from Newton's second law that the block moves with an acceleration $\vec{a}$.

If the block (and the force) moves through a displacement $\Delta\vec{r} = \Delta x\,\hat{\imath} = (x_f - x_i)\hat{\imath}$, the net work done on the block by the external net force $\sum \vec{F}$ is

$$\sum W = \int_{x_i}^{x_f} \sum F\,dx$$



7.4 Work Done by a Varying Force

Using Newton's second law, we substitute for the magnitude of the net force $\sum F = ma$ and then perform the following chain-rule manipulations on the integrand:

$$\sum W = \int_{x_i}^{x_f} ma\, dx = \int_{x_i}^{x_f} m \frac{dv}{dt} dx = \int_{x_i}^{x_f} m \frac{dv}{dx}\frac{dx}{dt} dx$$

$$= \int_{v_i}^{v_f} mv\, dv$$

$$\sum W = \frac{1}{2} m v_f^2 - \frac{1}{2} m v_i^2$$

where v_i is the speed of the block at $x = x_i$ and v_f is its speed at x_f.

7.5 Kinetic Energy and the Work–Kinetic Energy Theorem:

the kinetic energy K of a particle of mass m moving with a speed v is defined as:

$$K \equiv \frac{1}{2} m v^2$$

- Kinetic energy is a scalar quantity
- Kinetic energy has the same units as work.
- K is always positive .

$$\sum W = K_f - K_i = \Delta K \qquad (2)$$

Equation (2) is an important result known as the **work–kinetic energy theorem:** When work is done on a system and the only change in the system is in its speed, the net work done on the system equals the change in kinetic energy of the system.

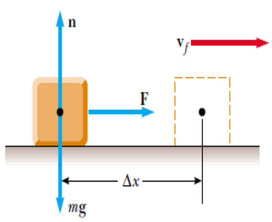
7.5 Kinetic Energy and the Work–Kinetic Energy Theorem:

- The speed of a system *increases* if the net work done on it is *positive* because the final kinetic energy is greater than the initial kinetic energy.
- The speed *decreases* if the net work is *negative* because the final kinetic energy is less than the initial kinetic energy.

7.5 Kinetic Energy and the Work–Kinetic Energy Theorem:

Example 7.7 A Block Pulled on a Frictionless Surface

A 6.0-kg block initially at rest is pulled to the right along a horizontal, frictionless surface by a constant horizontal force of 12 N. Find the speed of the block after it has moved 3.0 m.



7.8 Power

The time rate of energy transfer is called **power**.
We will focus on work as the energy transfer method in this discussion, but keep in mind that the notion of power is valid for *any* means of energy transfer. If an external force is applied to an object (which we assume acts as a particle), and if the work done by this force in the time interval Δt is W, then the **average power** during this interval is defined as

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

We define the instantaneous power P as the limiting value of the average power as Δt approaches zero:

$$P \equiv \lim_{\Delta t \to 0} \frac{W}{\Delta t} = \frac{dW}{dt} \qquad (3)$$

7.8 Power

We find from Equation (1) that $dW = \vec{F} \cdot d\vec{r}$. Therefore, the instantaneous power can be written:

$$P = \frac{dW}{dt} = \vec{F} \cdot \frac{d\vec{r}}{dt} = \vec{F} \cdot \vec{v}$$

Where $\frac{d\vec{r}}{dt} = \vec{v}$

In general, power is defined for any type of energy transfer. Therefore, the most general expression for power is

$$P = \frac{dE}{dt} \qquad (4)$$

The SI unit of power is joules per second (J/s), also called the watt (W) (after James Watt):

$$1W = 1J/s = 1kg \cdot m^2 / s^3$$

Example 7.12 Power Delivered by an Elevator Motor

An elevator car has a mass of 1 600 kg and is carrying passengers having a combined mass of 200 kg. A constant friction force of 4 000 N retards its motion upward, as shown in Figure.

(A) What power delivered by the motor is required to lift the elevator car at a constant speed of 3.00 m/s?

(B) What power must the motor deliver at the instant the speed of the elevator is v if the motor is designed to provide the elevator car with an upward acceleration of 1.00 m/s2?