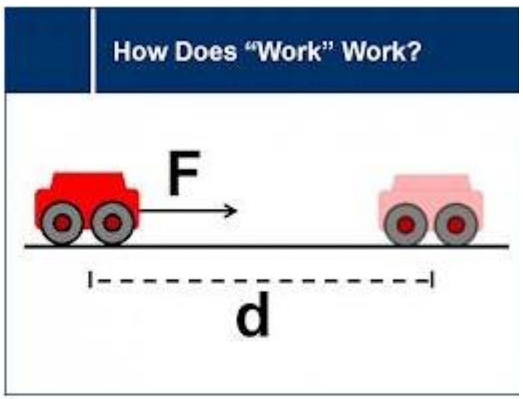
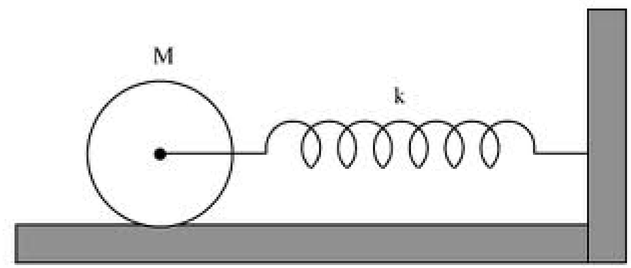
7 Kinetic Energy and Work





BY DR. WAJOOD DIERY

7.1 kinetic Energy

What is energy?

kinetic Energy

We define a new physical parameter to describe the state of motion of an object of mass m and speed v. We define its kinetic energy K as

$$\boxed{K = \frac{mv^2}{2}.}$$

SI unit is joule, symbol: **J** . $1\ \text{joule} = 1\ \text{J} = 1\ \text{kg} \cdot \text{m}^2/\text{s}^2$

Problem 1 page 147

When accelerated along a straight line at 2.8×10^{15} m/ s^2 in a machine, an electron (mass m= 9.1×10^{-31} kg) has an initial speed of 1.4×10^{7} m/ s and travels 5.8cm.

Find

(a) the final speed of the electron and

(b) the increase in its kinetic energy.

7.2 Work and kinetic energy

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.

If energy is transferred **to** the object $\Rightarrow$ work (W) is positive.

If energy is transferred **from** the object $\Rightarrow$ work $(W < 0)$ is negative.

Work has the SI unit of the joule, the same as kinetic energy

Work is a Scalar Quantity

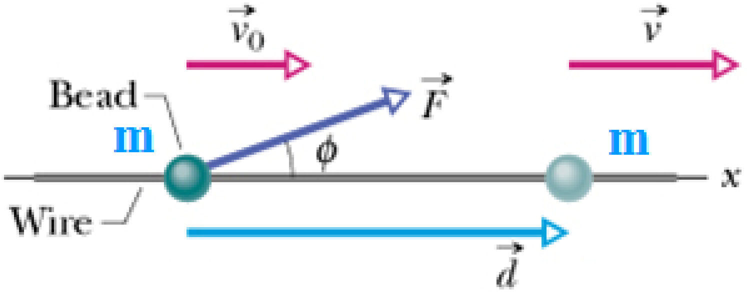
+ve Work → **energy transferred to the object**

-ve Work → **energy transferred from the object**

Finding an Expression for Work

$$W = Fd\cos\phi \qquad \text{(work done by a constant force)}$$

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



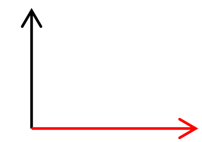
- Work has another unit

$$1\ \text{J} = 1\ \text{kg}\cdot\text{m}^2/\text{s}^2 = 1\ \text{N}\cdot\text{m} = 0.738\ \text{ft}\cdot\text{lb}.$$

$W = Fd\cos\phi$ (work done by a constant force)

1- If the angle ϕ between the force and displacmen $= 0^0 \Rightarrow W = Fd$

3- If the angle ϕ between the force and displacmen $= 90^0 \Rightarrow W = 0$

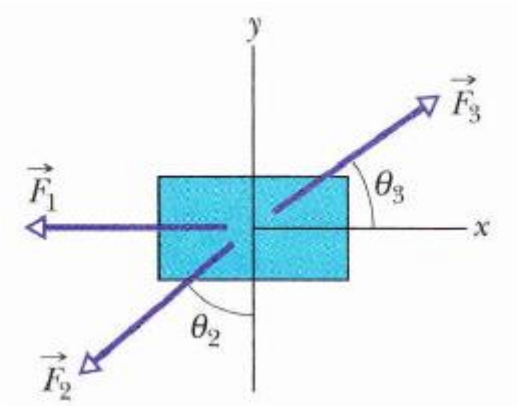


$$when\ \phi < 90^o \Rightarrow \cos\phi = +ve \Rightarrow W = +ve$$

5- If the angle ϕ between the force and displacmen $= 180^0 \Rightarrow W = -Fd$

$$when\ \phi > 90^\circ (up\ to\ 180^\circ) \Rightarrow \cos\phi = -ve \Rightarrow W = -ve$$

How to find the net Work done by several forces?



Net Work

Find the work done by each force and then sum those works

$$W_1 = F_1 d$$

$$W_2 = F_2 d$$

$$W_3 = F_3 d$$

$$W_{net} = W_1 + W_2 + W_3 + \cdots$$

Find the net forc $\vec{F}_{net}$ **then**

$$W_{net} = (F_{net}) d \cos\phi,$$

$where\ \phi\ is\ the\ angle\ between\ \vec{F}_{net}\ and\ \vec{d}$

Net Work: If we have several forces acting on a body there are two methods that can be used to calculate the net work W_{net}

Method 1: First calculate the work done by each force: W_A by force $\vec{F}_A$, W_B by force $\vec{F}_B$, and W_C by force $\vec{F}_C$. Then determine $W_{\text{net}} = W_A + W_B + W_C$.

Method 2: Calculate first $\vec{F}_{\text{net}} = \vec{F}_A + \vec{F}_B + \vec{F}_C$; then determine $W_{\text{net}} = \vec{F}_{\text{net}} \cdot \vec{d}$.

Work-Kinetic Energy Theorem

$$\boxed{\Delta K = K_f - K_i = W_{\text{net}}}$$

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

$$\begin{bmatrix}\text{Change in the kinetic} \\ \text{energy of a particle}\end{bmatrix} = \begin{bmatrix}\text{net work done on} \\ \text{the particle}\end{bmatrix}$$

If $W_{\text{net}} > 0 \rightarrow K_f > K_i$ $\Rightarrow$ **Energy increases**

If $W_{\text{net}} < 0 \rightarrow K_f < K_i$ $\Rightarrow$ **Energy decreases**

Sample Problem 7.02

Figure 7-4*a* shows two industrial spies sliding an initially stationary 225 kg floor safe a displacement $\vec{d}$ of magnitude 8.50 m, straight toward their truck. The push $\vec{F}_1$ of spy 001 is 12.0 N, directed at an angle of 30.0° downward from the horizontal; the pull $\vec{F}_2$ of spy 002 is 10.0 N, directed at 40.0° above the horizontal. The magnitudes and directions of these forces do not change as the safe moves, and the floor and safe make frictionless contact.

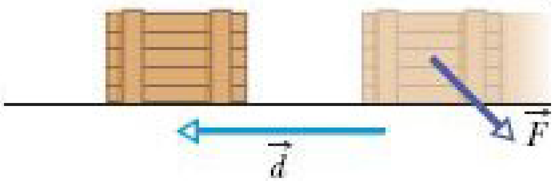
(a) What is the net work done on the safe by forces $\vec{F}_1$ and $\vec{F}_2$ during the displacement $\vec{d}$?

(b) During the displacement, what is the work W_g done on the safe by the gravitational force $\vec{F}_g$ and what is the work W_N done on the safe by the normal force $\vec{F}_N$ from the floor?

(c) The safe is initially stationary. What is its speed v_f at the end of the 8.50 m displacement?

Sample Problem 7.03

During a storm, a crate of crepe is sliding across a slick, oily parking lot through a displacement $\vec{d} = (-3.0 \text{ m})\hat{\text{i}}$ while a steady wind pushes against the crate with a force $\vec{F} = (2.0 \text{ N})\hat{\text{i}} + (-6.0 \text{ N})\hat{\text{j}}$. The situation and coordinate axes are shown in Fig. 7-5.



(a) How much work does this force do on the crate during the displacement?

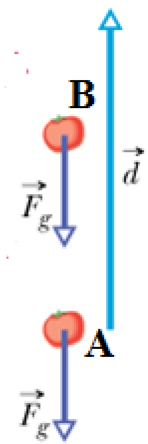
(b) If the crate has a kinetic energy of 10 J at the beginning of displacement $\vec{d}$, what is its kinetic energy at the end of $\vec{d}$?

7-3 Work done by the gravitational force

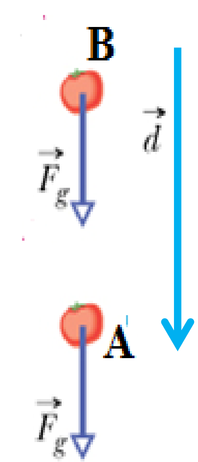
$$W_g = mgd\cos\phi \qquad \text{(work done by gravitational force)}$$

For a rising object, force $\vec{F}_g$ is directed opposite the displacement $\vec{d}$.

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



For falling object, force $\vec{F}_g$ is directed along the displacement $\vec{d}$



$$W_g = mgd\cos 0° = mgd(+1) = +mgd$$

Problem 18 p. 148

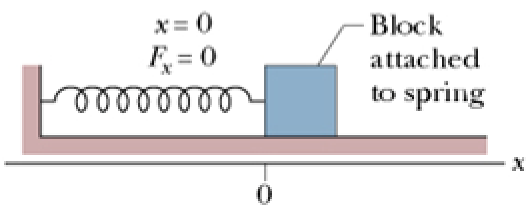
In 1975 the roof of Monteria's Velodrome, with a weight of 360 kN, was lifted by 10 cm so that it could be centered.

-How much work was done on the roof by the gravitational force?

7-4 Work done by a spring force

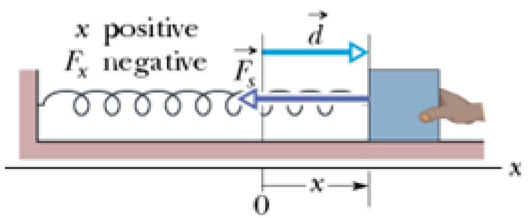
The Spring Force

Fig. a shows a spring in its relaxed state.



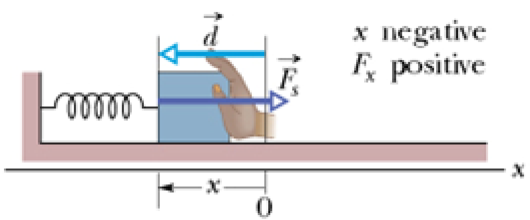
(a)

In fig. b we pull one end of the spring and stretch it by an amount d. The spring resists by exerting a force F on our hand in the opposite direction.



(b)

In fig. c we push one end of the spring and compress it by an amount d. Again the spring resists by exerting a force F on our hand in the opposite direction.



(c)

The *spring force* is given by

$$\vec{F}_s = -k\vec{d} \qquad \text{(Hooke's law)}$$

$$\vec{F}_s = -k\vec{d} \qquad \text{(Hooke's law)}$$

- The minus sign in Eq. 7-20 indicates that the direction of the spring force is always opposite the direction of the displacement of the spring

- The constant k is called the **spring constant** (or **force constant**)

- The SI unit for k is the newton per meter.

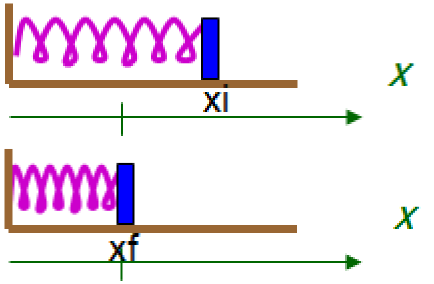
$$d = x_2 - x_1 \quad , \quad Let\ x_1 = 0\ and\ x_2 = x$$

$$\boxed{F_x = -kx \qquad \text{(Hooke's law)}}$$

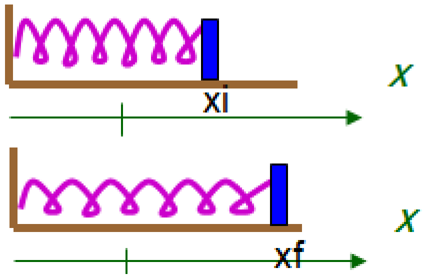
The Work Done by a Spring Force

$$\boxed{W_s = \tfrac{1}{2}kx_i^2 - \tfrac{1}{2}kx_f^2}$$

$-\text{If } x_i \succ x_f \Leftarrow W + ve$



$-\text{If } x_f \succ x_i \Leftarrow W - ve$



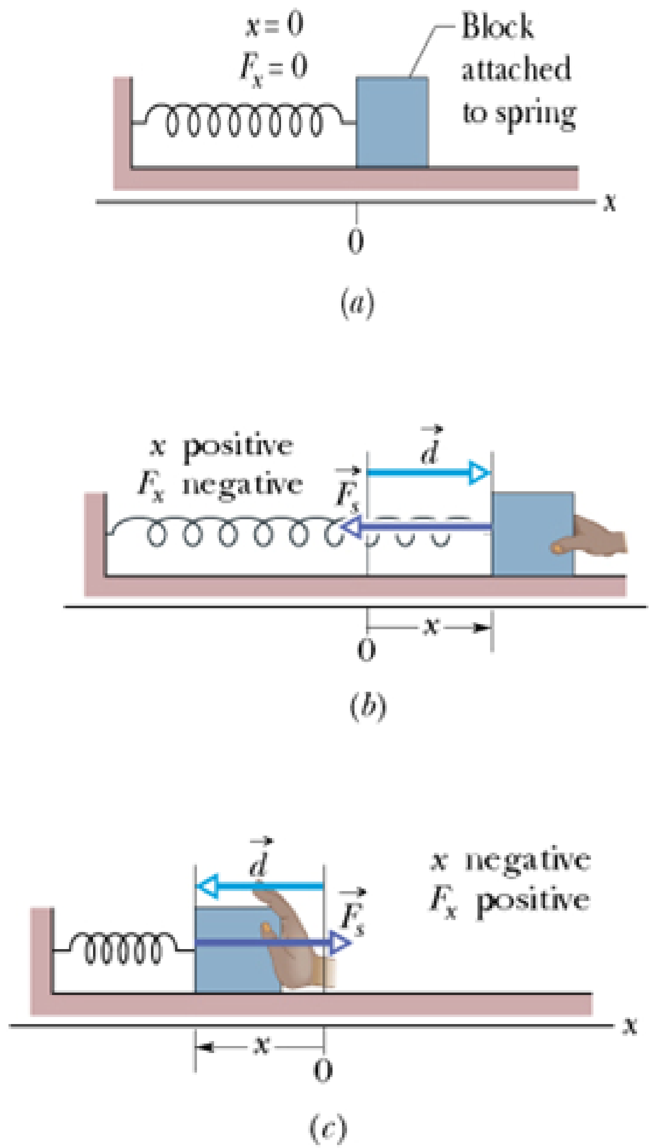
Work W_s is positive if the block ends up closer to the relaxed position ($x = 0$) than it was initially. It is negative if the block ends up farther away from $x = 0$. It is zero if the block ends up at the same distance from $x = 0$.

If $x_i = 0$ and if we call the final position x.

$$\boxed{W_s = -\tfrac{1}{2}kx^2}$$

Problem 27 p. 149

A spring and block are in the arrangement of Fig. 7-10 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 (a) x = +3.0 cm, (b) x = -3.0 cm, (c) x= -5.0 cm, and (d) x= -9.0 cm ?



7-6 Power

The time rate at which work is done by a force is said to be the **power**

Average power

$$P_{avg} = \frac{W}{\Delta t} \qquad \text{(average power).}$$

Instantaneous power

$$P = \frac{dW}{dt} \qquad \text{(instantaneous power).}$$

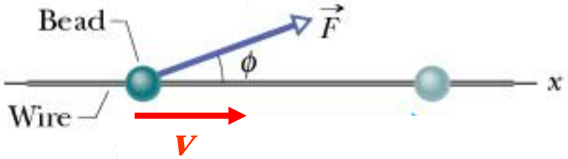
Unit of P : The SI unit of power is the watt. It is defined as the power of an engine that does work $W = 1$ J in a time $t = 1$ second.

A commonly used non-SI power unit is the horsepower (hp), defined as

1 hp = 746 W.

The kilowatt-hour The kilowatt-hour (kWh) is a unit of work. It is defined as the work performed by an engine of power $P = 1000$ W in a time $t = 1$ hour, $W = Pt = 1000 \times 3600 = 3.60 \times 10^6$ J. The kWh is used by electrical utility companies (check your latest electric bill).

$$P = \frac{dW}{dt} \quad \text{but} \quad W = Fd\cos\phi$$



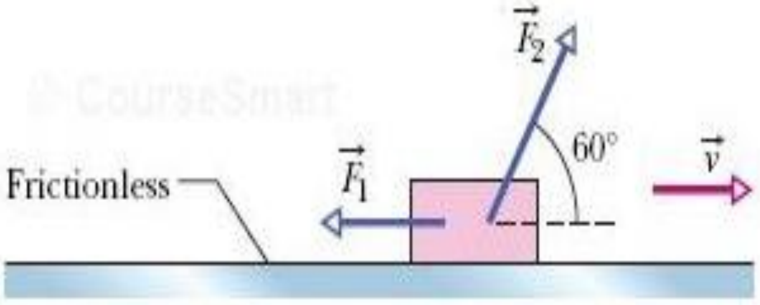
$$= \frac{d\,F\cos\phi\,dx}{dt}$$

$$= F\cos\phi\left(\frac{dx}{dt}\right) \Rightarrow \boxed{P = Fv\cos\phi}$$

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

Sample Problem 7.09

Figure 7-16 shows constant forces $\vec{F}_1$ and $\vec{F}_2$ acting on a box as the box slides rightward across a frictionless floor. Force $\vec{F}_1$ is horizontal, with magnitude 2.0 N; force $\vec{F}_2$ is angled upward by 60° to the floor and has magnitude 4.0 N. The speed v of the box at a certain instant is 3.0 m/s. What is the power due to each force acting on the box at that instant, and what is the net power? Is the net power changing at that instant?




THE
END