Chapter 6

Work and Energy

continued

Requested Seat reassignments (Sec. 1)

Gram	J14
Weber	C22
Hardecki	B5
Pilallis	B18
Murray	B19
White	B20
Ogden	C1
Phan	C2
Vites	C3
Mccrate	C4

Demonstrations

- Swinging mass, pendulum, collisions
- Ramps and slides
- Spinning mass inside toy truck

Clicker Question 6.2

Two balls of equal size are dropped from the same height from the roof of a building. One ball has twice the mass of the other. When the balls reach the ground, how do the kinetic energies of the two balls compare (ignoring air friction)?

a) The lighter one has one fourth as much kinetic energy as the other does.

b) The lighter one has one half as much kinetic energy as the other does.

c) The lighter one has the same kinetic energy as the other does.

d) The lighter one has twice as much kinetic energy as the other does.

e) The lighter one has four times as much kinetic energy as the other does.

$\boxed{\text{Hint: what is the acceleration and } v_{\mathrm{f}} \text{ of each mass?}}$

Clicker Question 6.2

Two balls of equal size are dropped from the same height from the roof of a building. One ball has twice the mass of the other. When the balls reach the ground, how do the kinetic energies of the two balls compare?

a) The lighter one has one fourth as much kinetic energy as the other does.

b) The lighter one has one half as much kinetic energy as the other does.

c) The lighter one has the same kinetic energy as the other does.

d) The lighter one has twice as much kinetic energy as the other does.

e) The lighter one has four times as much kinetic energy as the other does.

Acceleration (g), and v_f

are the same for both masses.

$\mathrm{KE} = \frac{1}{2} m v_\mathrm{f}^2$, proportional to mass.

$$\mathrm{KE}_1 = \tfrac{1}{2} m_1 v_\mathrm{f}^2;$$

$$\mathrm{KE}_2 = \tfrac{1}{2} m_2 v_\mathrm{f}^2 = \tfrac{1}{2}(2m_1) v_\mathrm{f}^2$$

$$= 2\left[\tfrac{1}{2} m_1 v_\mathrm{f}^2\right] = 2\mathrm{KE}_1$$

$$\mathrm{KE}_1 = \tfrac{1}{2}\mathrm{KE}_2$$

6.3 *Gravitational Potential Energy*

GRAVITATIONAL POTENTIAL ENERGY

Energy of mass m due to its position relative to the surface of the earth.
Position measured by the height h of mass relative to an arbitrary zero level:

$$\boxed{\mathrm{PE} = mgh}$$

PE replaces Work by gravity in the Work-Energy Theorem

Work-Energy Theorem becomes Mechanical Energy Conservation:

$$\boxed{\begin{gathered}\mathrm{KE_f} + \mathrm{PE_f} = \mathrm{KE_0} + \mathrm{PE_0} \\ \mathrm{E_f} = \mathrm{E_0}\end{gathered}}$$

Initial total energy, $\mathrm{E_0} = \mathrm{KE_0} + \mathrm{PE_0}$ doesn't change.
It is the same as final total energy, $\mathrm{E_f} = \mathrm{KE_f} + \mathrm{PE_f}$.

Another way (equivalent) to look at Mechanical Energy Conservation:

$$\left(\mathrm{KE_f} - \mathrm{KE_0}\right) + \left(\mathrm{PE_f} - \mathrm{PE_0}\right) = 0$$

$$\boxed{\Delta\mathrm{KE} \quad + \quad \Delta\mathrm{PE} \quad = 0}$$

Any increase (decrease) in KE is balanced by a decrease (increase) in PE.

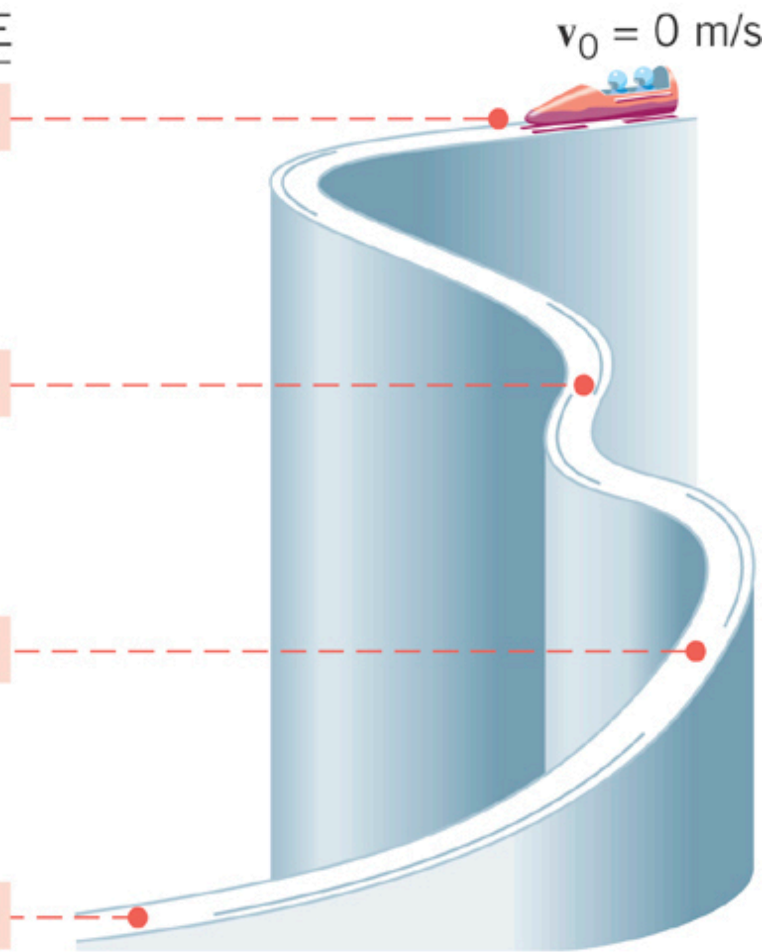
These are used if only Conservative Forces act on the mass.
(Gravity, Ideal Springs, Electric forces)

6.5 The Conservation of Mechanical Energy

Sliding without friction: only gravity does work.

Normal force of ice is always perpendicular to displacements.

KE	PE	E = KE + PE
0 J	600 000 J	600 000 J
200 000 J	400 000 J	600 000 J
400 000 J	200 000 J	600 000 J
600 000 J	0 J	600 000 J



Clicker Question 6.3

You are investigating the safety of a playground slide. You are interested in finding out what the maximum speed will be of children sliding on it when the conditions make it very slippery (assume frictionless). The height of the slide is 2.5 m. What is that maximum speed of a child if she starts from rest at the top?

a) 1.9 m/s

b) 2.5 m/s

c) 4.9 m/s

d) 7.0 m/s

e) 9.8 m/s

Clicker Question 6.3

You are investigating the safety of a playground slide. You are interested in finding out what the maximum speed will be of children sliding on it when the conditions make it very slippery (assume frictionless). The height of the slide is 2.5 m. What is that maximum speed of a child if she starts from rest at the top?

a) 1.9 m/s

b) 2.5 m/s

c) 4.9 m/s

d) 7.0 m/s

e) 9.8 m/s

$$E_0 = mgh; \quad E_f = \tfrac{1}{2} m v_f^2$$

$$E_0 = E_f \Rightarrow mgh = \tfrac{1}{2} m v_f^2$$

$$v_f = \sqrt{2gh} = \sqrt{2(9.8)(2.5)}\ \mathrm{m/s}$$

$$= 7.0\ \mathrm{m/s}$$

6.4 Conservative Versus Nonconservative Forces

In many situations both conservative and non-conservative forces act simultaneously on an object, so the work done by the net external force can be written as

$$W_{\text{Net}} = W_{\text{C}} + W_{\text{NC}}$$

W_{C} = work by conservative force

such as work by gravity W_{G}

But replacing W_{C} with $-(\text{PE}_{\text{f}} - \text{PE}_0)$

Work-Energy Theorem becomes:

$$\boxed{\begin{aligned} \text{KE}_{\text{f}} + \text{PE}_{\text{f}} &= \text{KE}_0 + \text{PE}_0 + W_{\text{NC}} \\ \text{E}_{\text{f}} &= \text{E}_0 + W_{\text{NC}} \end{aligned}}$$

work by non-conservative forces will add or remove energy from the mass

$$\text{E}_{\text{f}} = \text{KE}_{\text{f}} + \text{PE}_{\text{f}} \neq \text{E}_0 = \text{KE}_0 + \text{PE}_0$$

Another (equivalent) way to think about it:

$$\boxed{\begin{aligned} \left(\text{KE}_{\text{f}} - \text{KE}_0\right) + \left(\text{PE}_{\text{f}} - \text{PE}_0\right) &= W_{\text{NC}} \\ \Delta\text{KE} + \Delta\text{PE} &= W_{\text{NC}} \end{aligned}}$$

if non-conservative forces do work on the mass, energy changes will not sum to zero

6.5 The Conservation of Mechanical Energy

But all you need is this:

$$\boxed{\mathrm{KE_f} + \mathrm{PE_f} = \mathrm{KE_0} + \mathrm{PE_0} + W_{\mathrm{NC}}}$$

non-conservative forces add or remove energy

$$\boxed{\text{If } W_{\mathrm{NC}} \neq 0, \text{ then } \mathrm{E_f} \neq \mathrm{E_0}}$$

If the net work on a mass by non-conservative forces is zero, then its total energy does not change:

$$\boxed{\text{If } W_{\mathrm{NC}} = 0, \text{ then } \mathrm{E_f} = \mathrm{E_0}}$$

$$\boxed{\mathrm{KE_f} + \mathrm{PE_f} = \mathrm{KE_0} + \mathrm{PE_0}}$$

Clicker Question 6.3

A mass has a total energy of 100 J. Then a kinetic frictional force does –50 J of work on the mass. What is the resulting total energy of the mass?

a) 0 J

b) 50 J

c) 100 J

d) 150 J

e) –50 J

Clicker Question 6.3

A mass has a total energy of 100 J. Then a non-conservative force does –50 J of work on the mass. What is the resulting total energy of the mass?

a) 0 J

$\boxed{\text{b) } 50\,\text{J}}$

c) 100 J

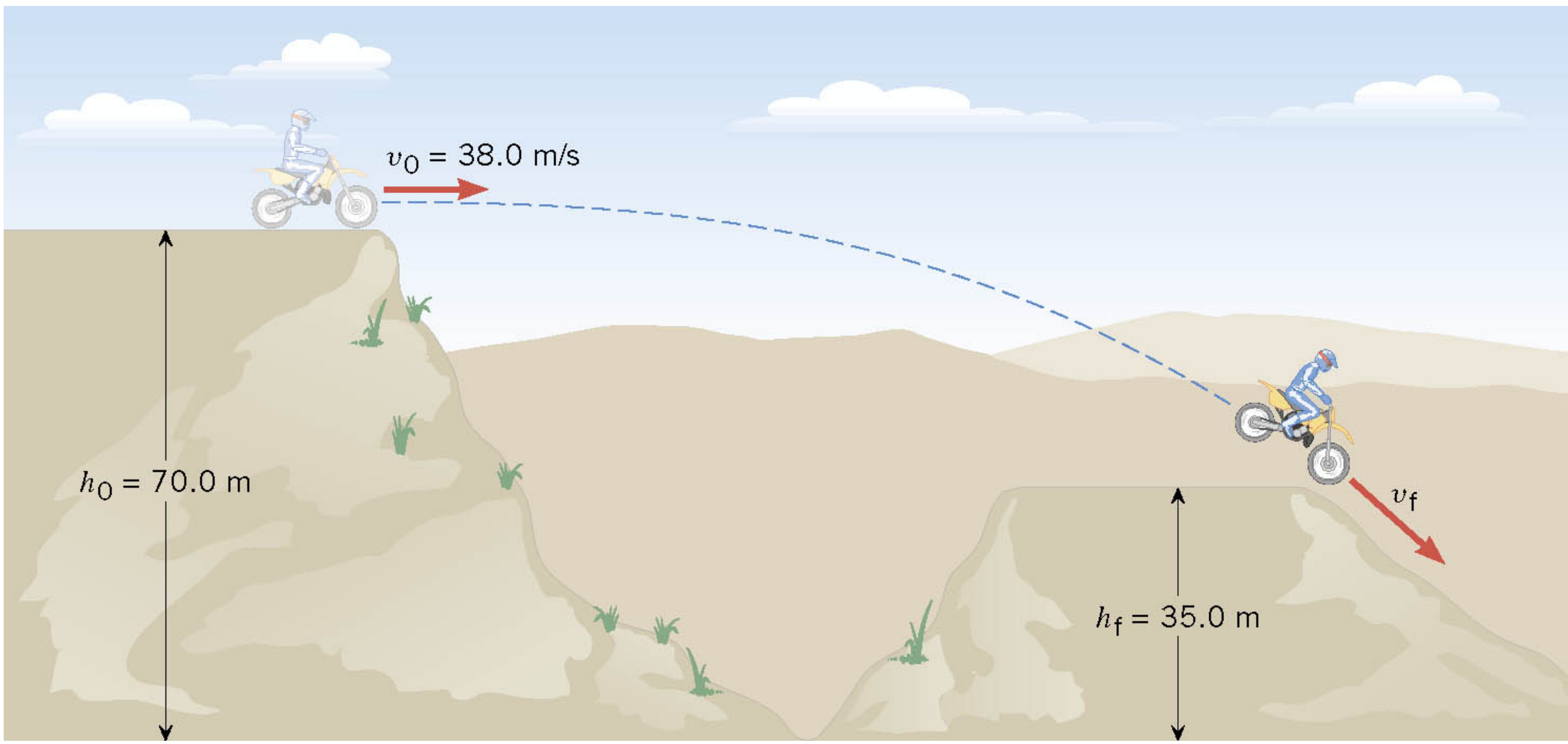
d) 150 J

e) –50 J

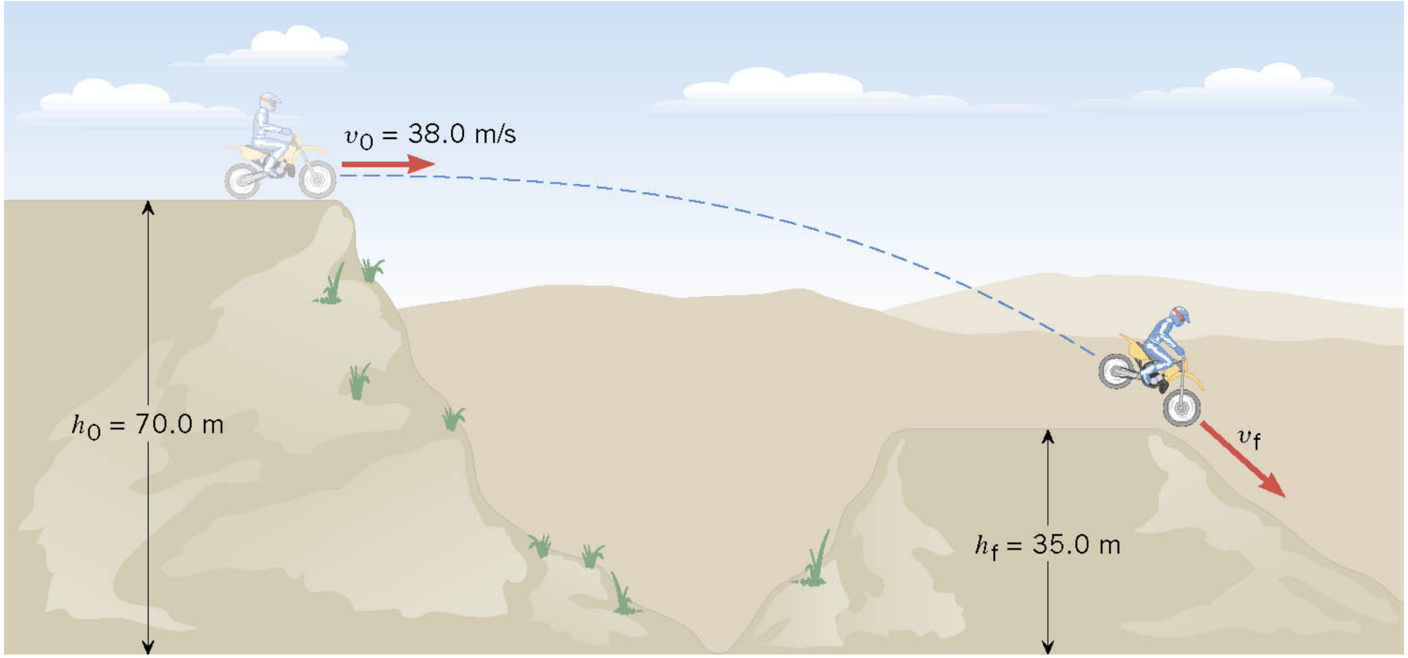
$$\boxed{\begin{aligned} &\mathrm{E_f} - \mathrm{E_0} = W_{\mathrm{NC}} \\ &\mathrm{E_f} = \mathrm{E_0} + W_{\mathrm{NC}} = 100\,\mathrm{J} + (-50\,\mathrm{J}) = 50\,\mathrm{J} \end{aligned}}$$

Example 8 A Daredevil Motorcyclist

A motorcyclist is trying to leap across the canyon by driving horizontally off a cliff 38.0 m/s. Ignoring air resistance, find the speed with which the cycle strikes the ground on the other side.



6.5 The Conservation of Mechanical Energy

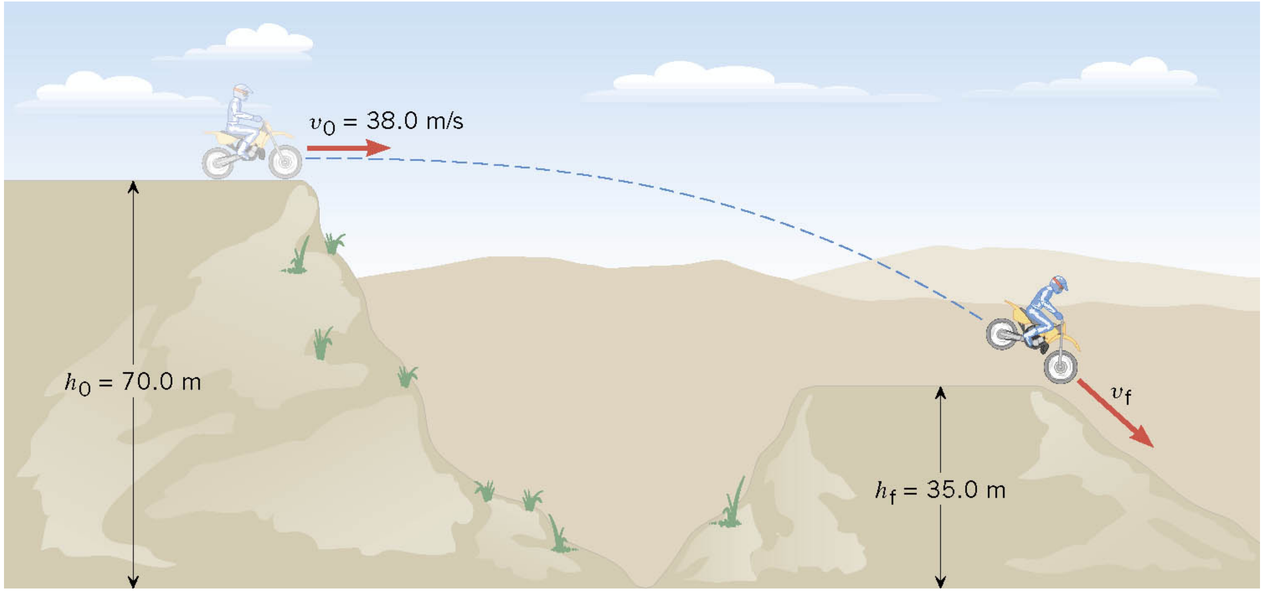


$$E_f = E_o$$

$$mgh_f + \tfrac{1}{2}mv_f^2 = mgh_0 + \tfrac{1}{2}mv_0^2$$

$$gh_f + \tfrac{1}{2}v_f^2 = gh_0 + \tfrac{1}{2}v_0^2$$

6.5 The Conservation of Mechanical Energy



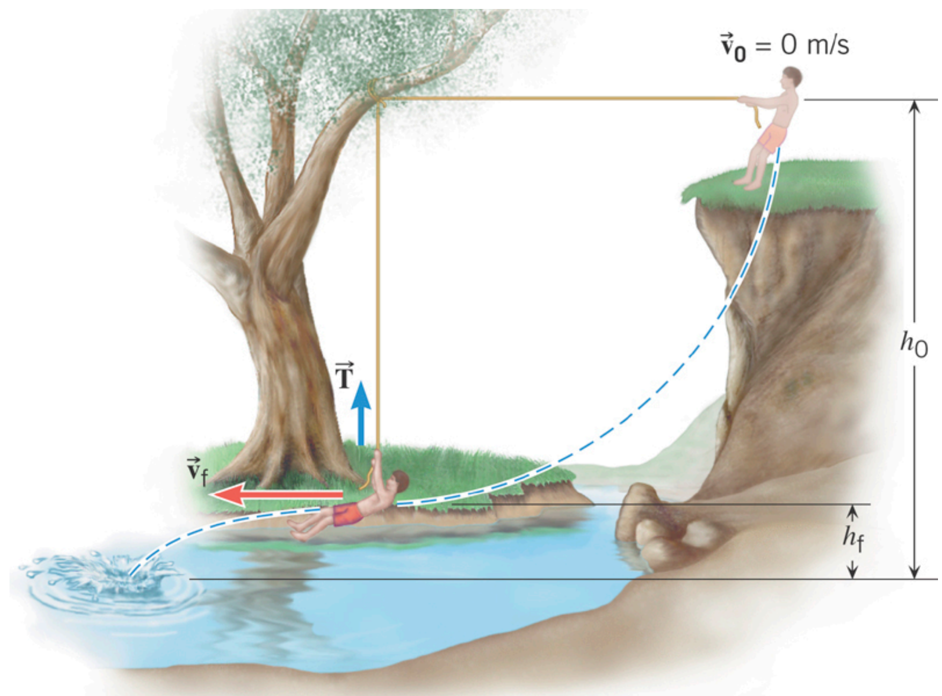
$$gh_f + \tfrac{1}{2}v_f^2 = gh_0 + \tfrac{1}{2}v_0^2$$

$$v_f = \sqrt{2g\left(h_0 - h_f\right) + v_0^2}$$

$$v_f = \sqrt{2\left(9.8\,\mathrm{m/s^2}\right)\left(35.0\,\mathrm{m}\right) + \left(38.0\,\mathrm{m/s}\right)^2} = 46.2\,\mathrm{m/s}$$

Conceptual Example 9 The Favorite Swimming Hole

The person starts from rest, with the rope held in the horizontal position, swings downward, and then lets go of the rope, with no air resistance. Two forces act on him: gravity and the tension in the rope.

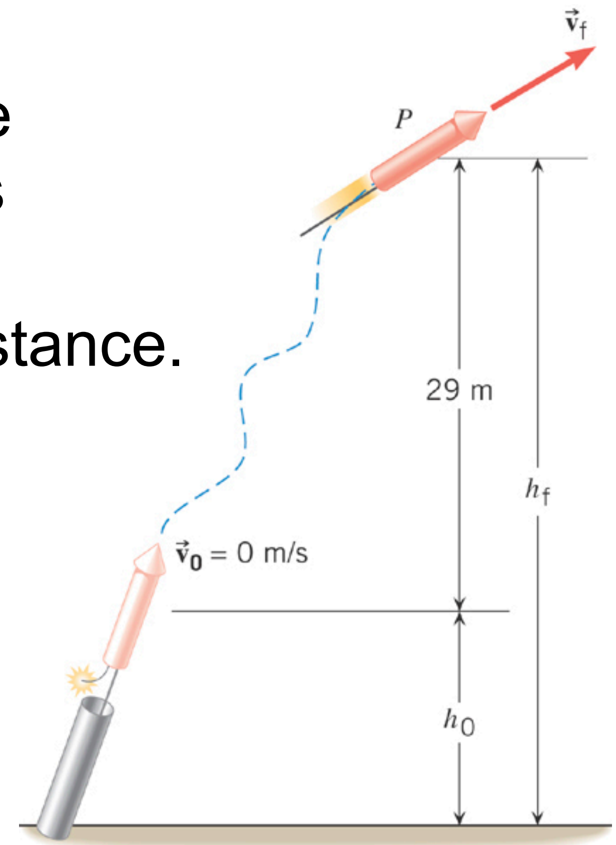


Note: tension in rope is always perpendicular to displacement, and so, does no work on the mass.

The principle of conservation of energy can be used to calculate his final speed.

Example 11 Fireworks

Assuming that the nonconservative force generated by the burning propellant does 425 J of work, what is the final speed of the rocket (m = 0.2kg). Ignore air resistance.



$$E_f = E_0 + W_{NC}$$

$$W_{NC} = \left(mgh_f + \tfrac{1}{2}mv_f^2\right) - \left(mgh_0 + \tfrac{1}{2}mv_0^2\right)$$

$$= mg\left(h_f - h_0\right) + \tfrac{1}{2}mv_f^2 + 0$$

$$v_f^2 = 2W_{NC}/m - 2g\left(h_f - h_0\right)$$

$$= 2\left(425\text{ J}\right)/\left(0.20\text{ kg}\right) - 2\left(9.80\,\text{m/s}^2\right)\left(29.0\text{ m}\right)$$

$$v_f = 61\text{ m/s}$$

6.7 Power

DEFINITION OF AVERAGE POWER

Average power is the rate at which work is done, and it is obtained by dividing the work by the time required to perform the work.

$$\overline{P} = \frac{\text{Work}}{\text{Time}} = \frac{W}{t}$$

$$\text{joule/s} = \text{watt (W)}$$

Note: 1 horsepower = 745.7 watts

$$\overline{P} = \frac{\text{Change in energy}}{\text{Time}}$$

$$\overline{P} = \frac{W}{t} = \frac{Fs}{t} = F\left(\frac{s}{t}\right) = F\overline{v}$$

Table 6.4 **Human Metabolic Rates**[a]

Activity	Rate (watts)
Running (15 km/h)	1340 W
Skiing	1050 W
Biking	530 W
Walking (5 km/h)	280 W
Sleeping	77 W

[a]For a young 70-kg male.

6.8 *Other Forms of Energy and the Conservation of Energy*

THE PRINCIPLE OF CONSERVATION OF ENERGY

Energy can neither be created not destroyed, but can only be converted from one form to another.

Heat energy is the kinetic or vibrational energy of molecules. The result of a non-conservative force is often to remove mechanical energy and transform it into heat.

Examples of heat generation: sliding friction, muscle forces.