Chapter 6

Work and Energy

6.4 Conservative Versus Nonconservative Forces

DEFINITION OF A CONSERVATIVE FORCE

Version 1 A force is conservative when the work it does on a moving object is independent of the path between the object's initial and final positions.

Version 2 A force is conservative when it does no work on an object moving around a closed path, starting and finishing at the same point.

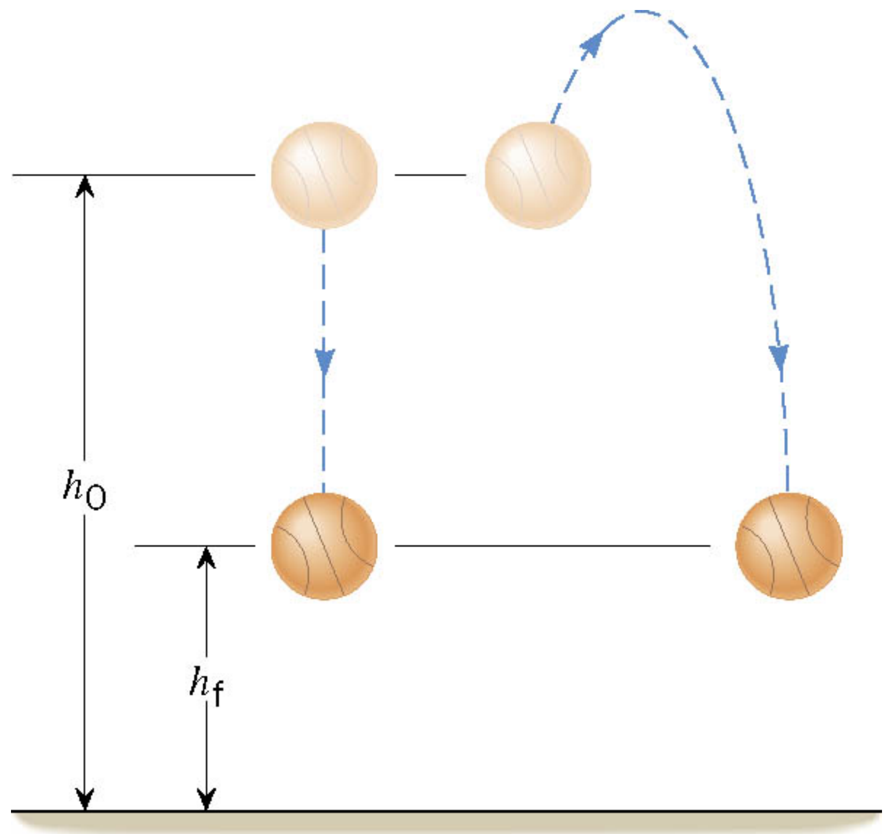
6.4 Conservative Versus Nonconservative Forces

Table 6.2 **Some Conservative and Nonconservative Forces**

Conservative Forces
Gravitational force (Ch. 4)
Elastic spring force (Ch. 10)
Electric force (Ch. 18, 19)
Nonconservative Forces
Static and kinetic frictional forces
Air resistance
Tension
Normal force
Propulsion force of a rocket

Version 1 A force is conservative when the work it does on a moving object is independent of the path between the object's initial and final positions.

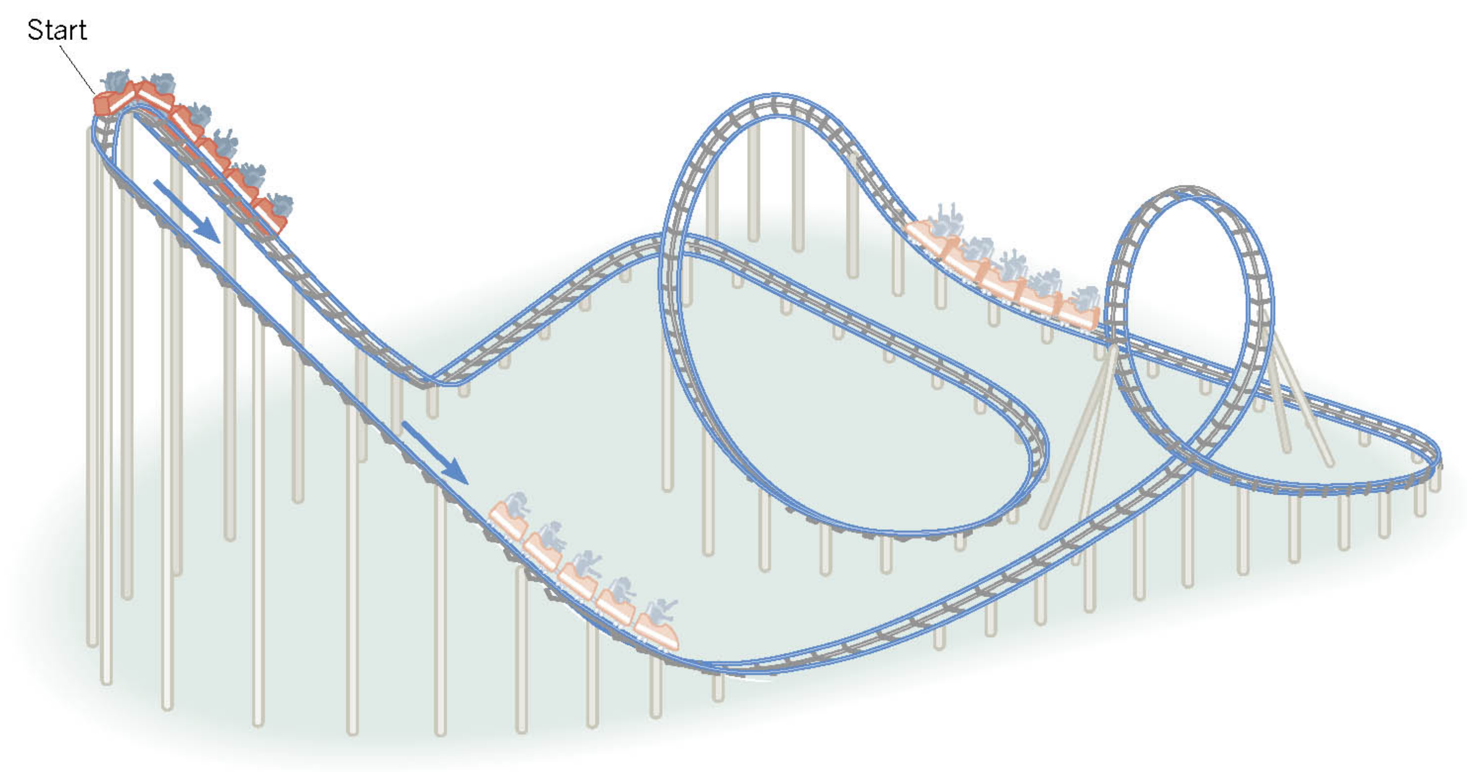
$$W_{\text{gravity}} = mg\left(h_o - h_f\right)$$



6.4 Conservative Versus Nonconservative Forces

Version 2 A force is conservative when it does no work on an object moving around a closed path, starting and finishing at the same point.

$$W_{\text{gravity}} = mg\left(h_o - h_f\right) \qquad h_o = h_f \rightarrow W_{\text{gravity}} = 0$$



6.4 Conservative Versus Nonconservative Forces

An example of a nonconservative force is the kinetic frictional force.

$$W = (F\cos\theta)s = f_k \cos 180^\circ s = -f_k s$$

The work done by the kinetic frictional force is always negative. Thus, it is impossible for the work it does on an object that moves around a closed path to be zero.

The concept of potential energy is not defined for a nonconservative force.

6.4 Conservative Versus Nonconservative Forces

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

$$W = W_c + W_{nc}$$

$$W = \mathrm{KE_f} - \mathrm{KE_o} = \Delta\mathrm{KE}$$

$$W_c = W_{\text{gravity}} = mgh_o - mgh_f = \mathrm{PE_o} - \mathrm{PE_f} = -\Delta\mathrm{PE}$$

6.4 Conservative Versus Nonconservative Forces

$$W = W_c + W_{nc}$$

$$\Delta \mathrm{KE} = -\Delta \mathrm{PE} + W_{nc}$$

A different version of the WORK-ENERGY THEOREM

$$W_{nc} = \Delta \mathrm{KE} + \Delta \mathrm{PE}$$

6.5 The Conservation of Mechanical Energy

$$W_{nc} = \Delta \mathrm{KE} + \Delta \mathrm{PE} = \left(\mathrm{KE}_\mathrm{f} - \mathrm{KE}_\mathrm{o}\right) + \left(\mathrm{PE}_\mathrm{f} - \mathrm{PE}_\mathrm{o}\right)$$

$$W_{nc} = \left(\mathrm{KE}_\mathrm{f} + \mathrm{PE}_\mathrm{f}\right) - \left(\mathrm{KE}_\mathrm{o} + \mathrm{PE}_\mathrm{o}\right)$$

$$W_{nc} = \mathrm{E}_\mathrm{f} - \mathrm{E}_\mathrm{o} = \Delta \mathrm{E}$$

$\mathrm{E} = \mathrm{KE} + \mathrm{PE}$ ➔ the total mechanical energy

If the net work on an object by nonconservative forces is zero, then its energy does not change:

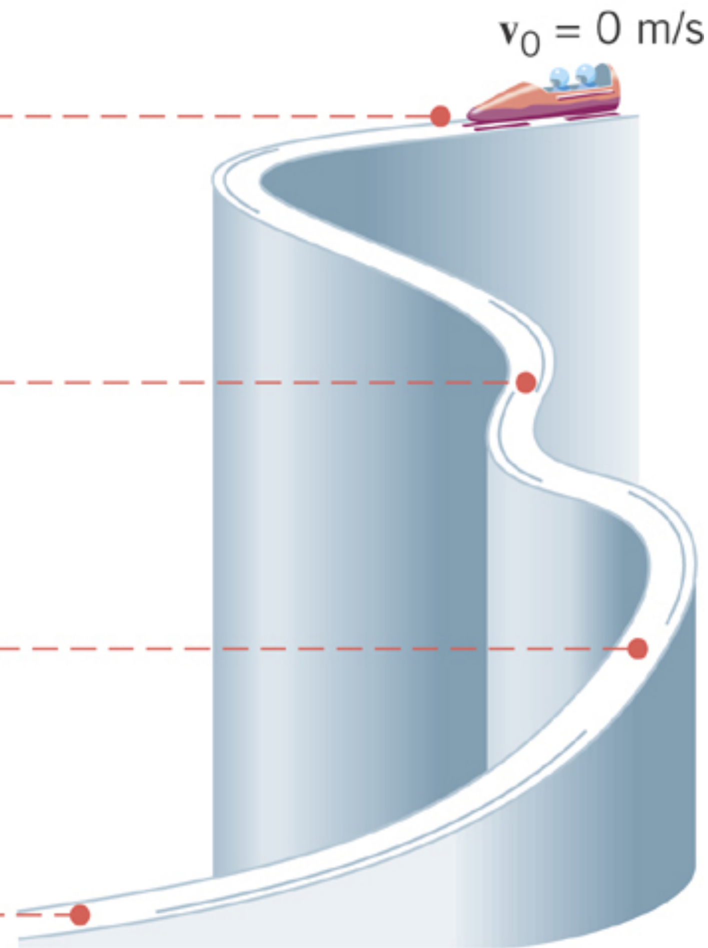
$$\mathrm{E}_\mathrm{f} = \mathrm{E}_\mathrm{o}$$

THE PRINCIPLE OF CONSERVATION OF MECHANICAL ENERGY

The total mechanical energy (E = KE + PE) of an object remains constant as the object moves, provided that the net work done by external nonconservative forces is zero.

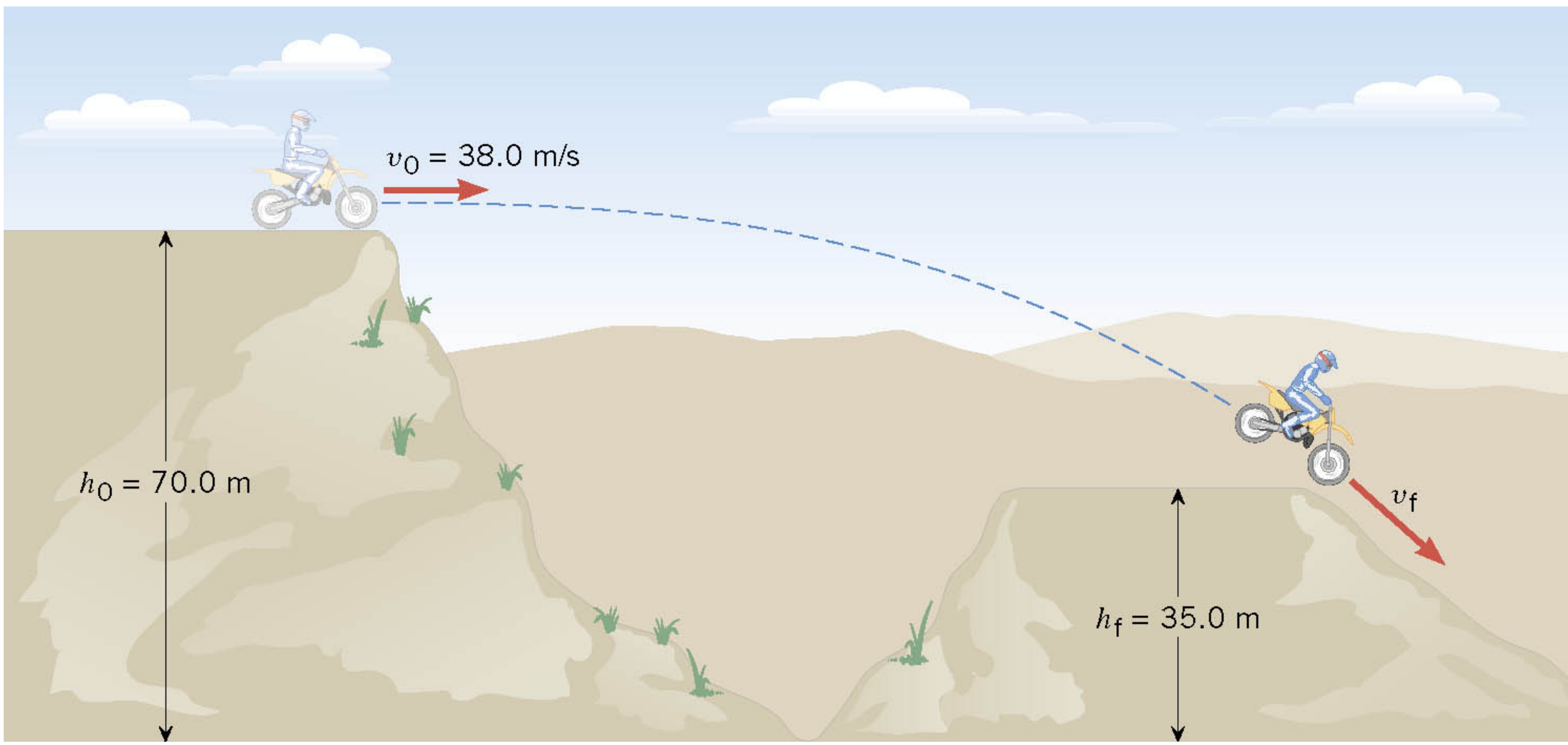
6.5 The Conservation of Mechanical Energy

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

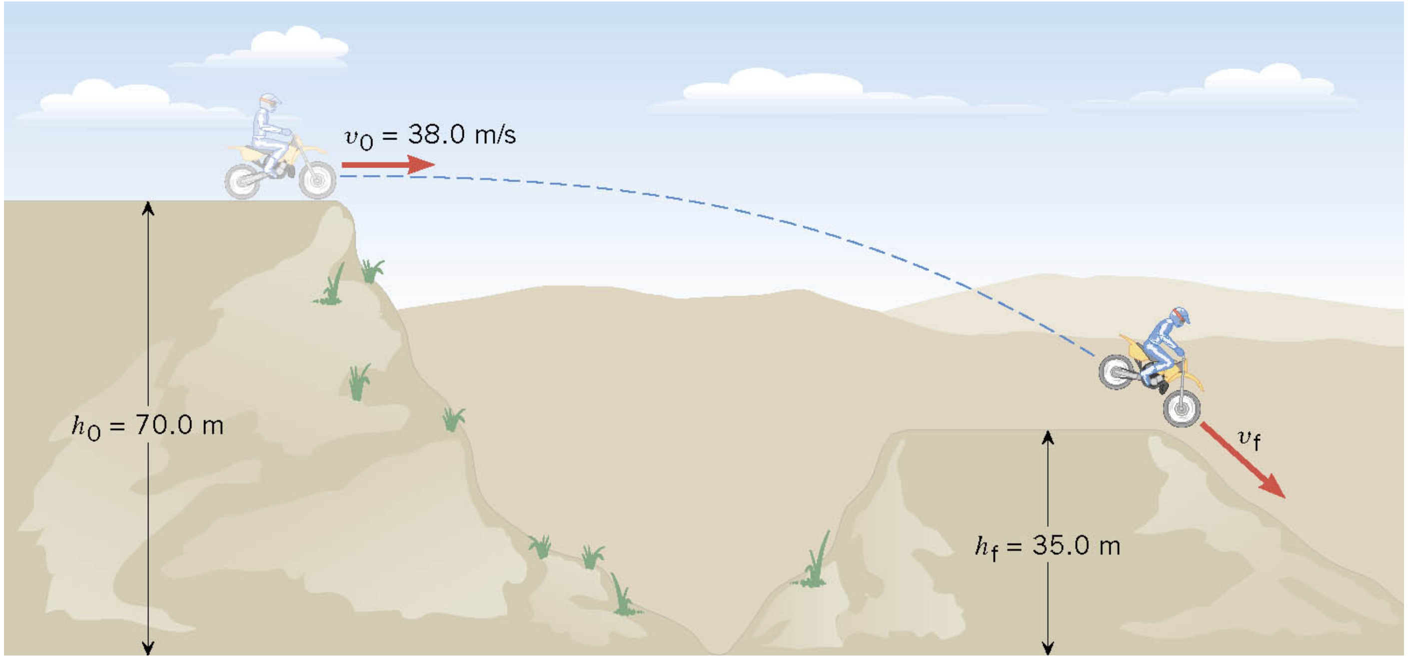


Example 8 A Daredevil Motorcyclist

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

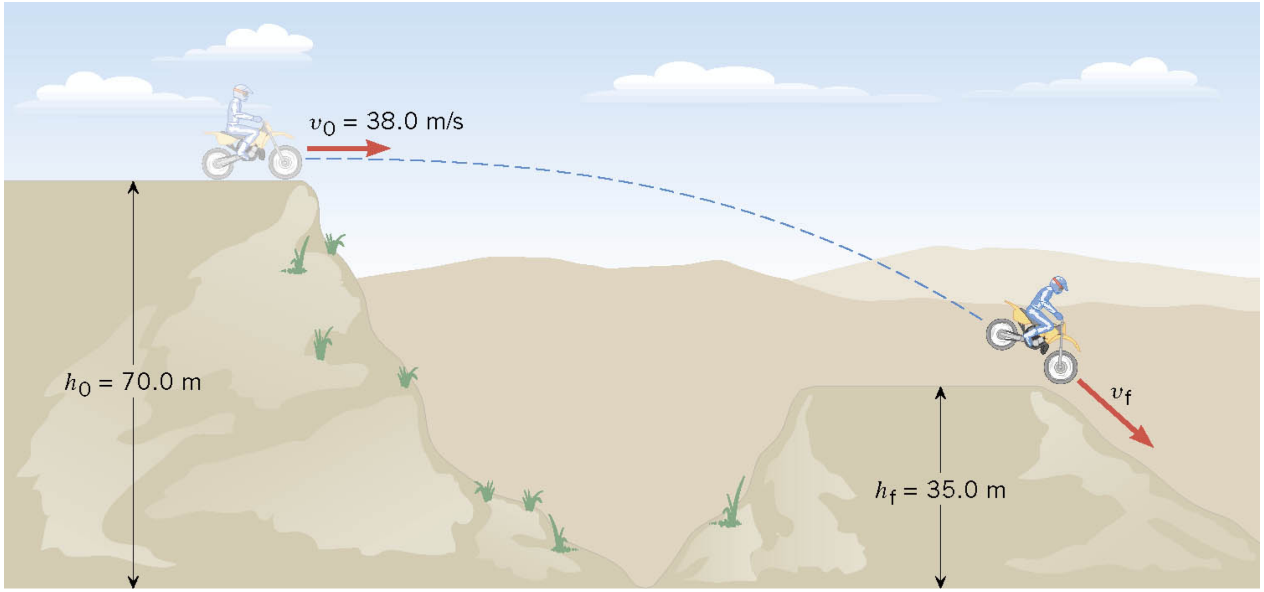


$$E_f = E_o$$

$$mgh_f + \tfrac{1}{2}mv_f^2 = mgh_o + \tfrac{1}{2}mv_o^2$$

$$gh_f + \tfrac{1}{2}v_f^2 = gh_o + \tfrac{1}{2}v_o^2$$

6.5 The Conservation of Mechanical Energy



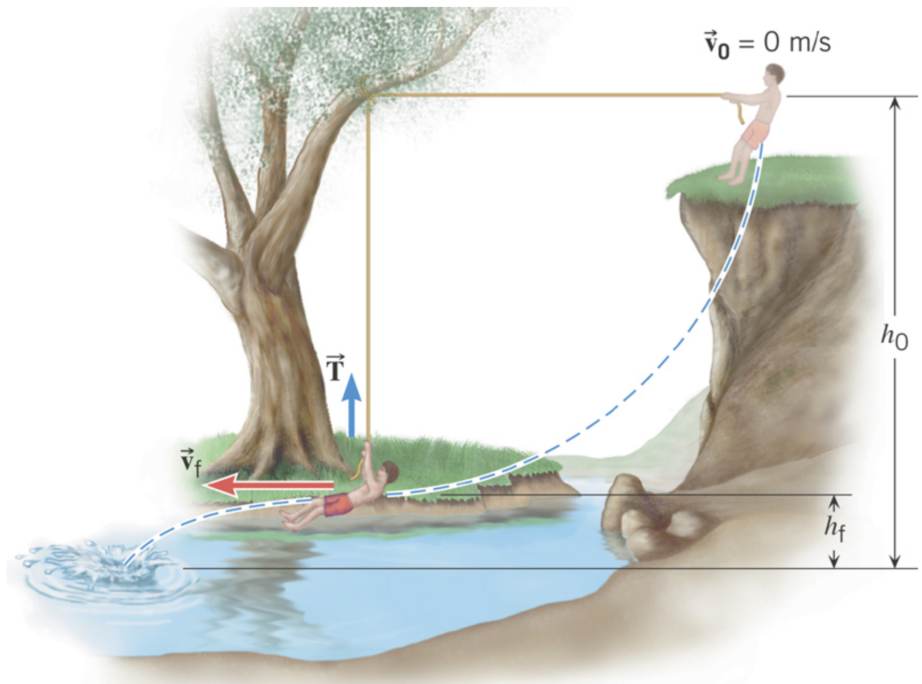
$$gh_f + \tfrac{1}{2}v_f^2 = gh_o + \tfrac{1}{2}v_o^2$$

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

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

Conceptual Example 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. Three forces act on him: his weight, the tension in the rope, and the force of air resistance.

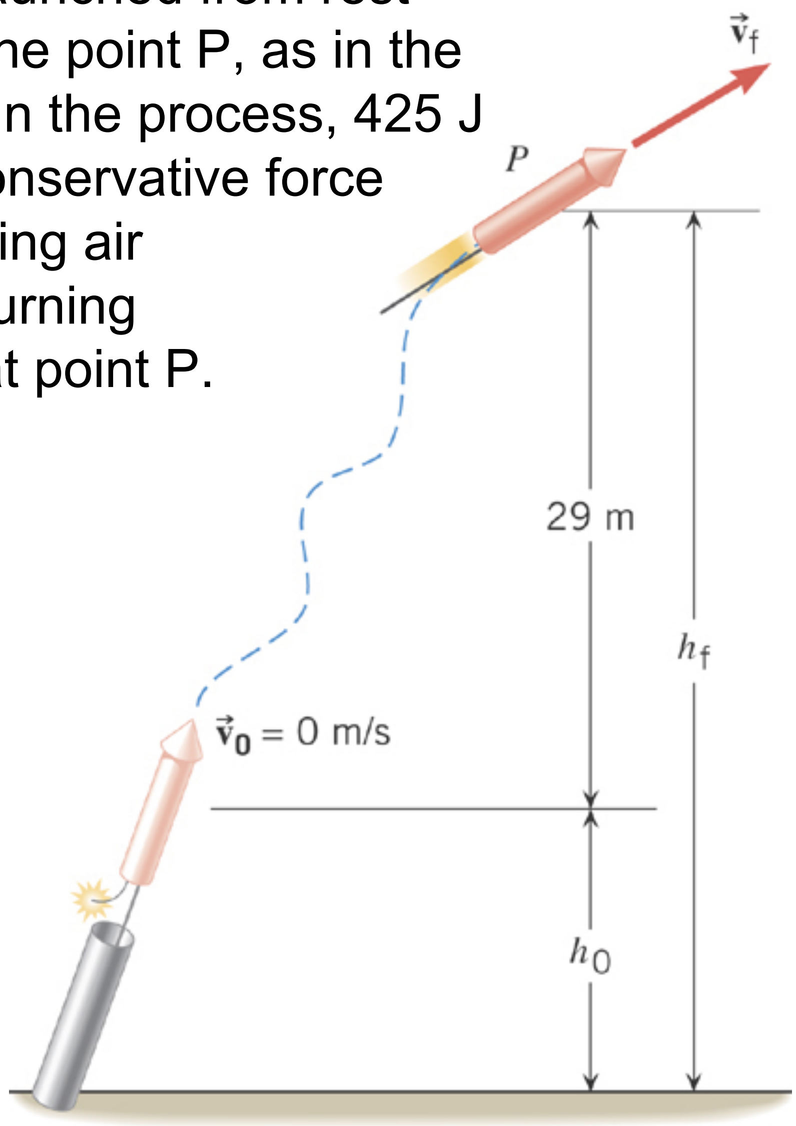


Can the principle of conservation of energy be used to calculate his final speed?

6.6 *Nonconservative Forces and the Work-Energy Theorem*

Example of a nonconservative force problem: **Fireworks**

A 0.20 kg rocket in a fireworks display is launched from rest and follows an erratic flight path to reach the point P, as in the figure. P is 29 m above the starting point. In the process, 425 J of work is done on the rocket by the nonconservative force generated by the burning propellant. Ignoring air resistance and the mass loss due to the burning propellant, find the speed v_f of the rocket at point P.



THE WORK-ENERGY THEOREM

$$W_{nc} = E_f - E_o$$

$$W_{nc} = \left(mgh_f + \tfrac{1}{2}mv_f^2\right) - \left(mgh_o + \tfrac{1}{2}mv_o^2\right)$$

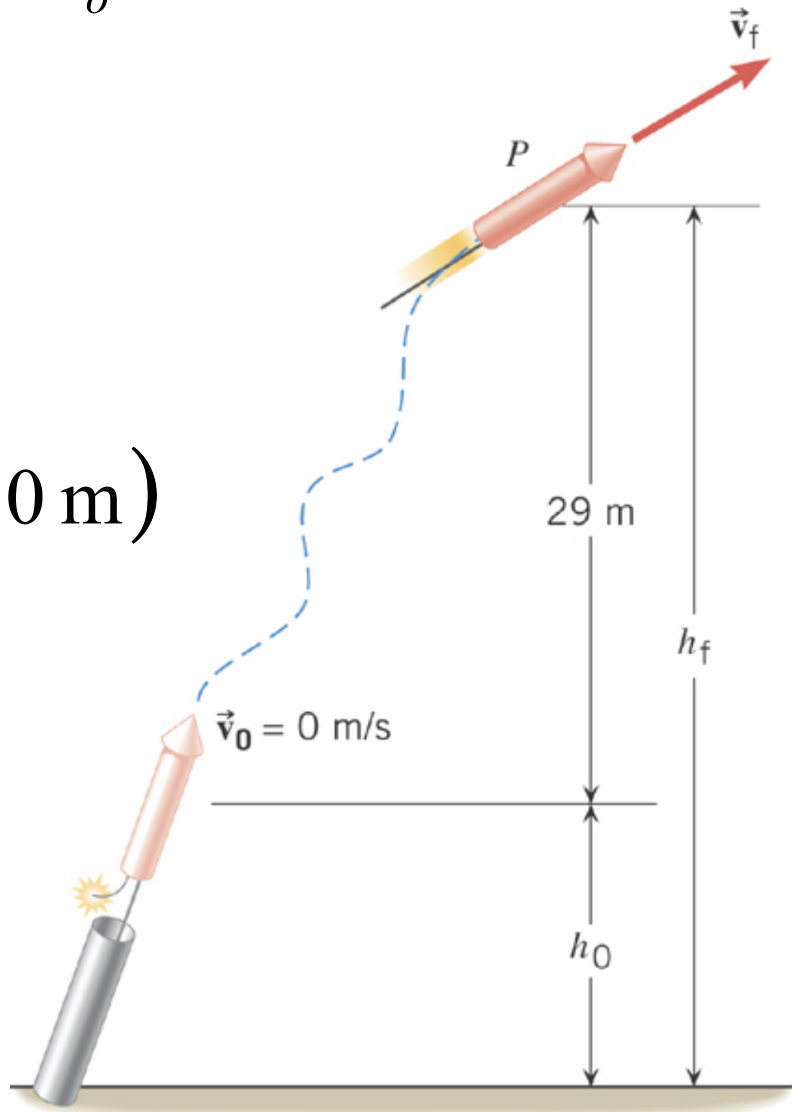
6.6 Nonconservative Forces and the Work-Energy Theorem

$$W_{nc} = mgh_f - mgh_o + \tfrac{1}{2}mv_f^2 - \tfrac{1}{2}mv_o^2$$

$$W_{nc} = mg\left(h_f - h_o\right) + \tfrac{1}{2}mv_f^2$$

$$425\,\text{J} = (0.20\,\text{kg})(9.80\,\text{m/s}^2)(29.0\,\text{m}) + \tfrac{1}{2}(0.20\,\text{kg})v_f^2$$

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



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.

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

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

6.7 Power

From the work-energy theorem, doing work results in a change in energy for the system, so alternatively:

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

$$1\text{ horsepower} = 550\text{ foot}\cdot\text{pounds/second} = 745.7\text{ watts}$$

Another way to express the power generated by a force acting on an object moving at some average speed,

$$\overline{P} = F\overline{v}$$

6.7 Power

Table 6.4 Human Metabolic Rates[a]

Activity	Rate (watts)	kcal/hour
Running (15 km/h)	1340 W	1160
Skiing	1050 W	905
Biking	530 W	457
Walking (5 km/h)	280 W	241
Sleeping	77 W	66

[a]For a young 70-kg male.

"1 calorie" ➔ 1 kcal = 4186 J

1 kcal/hour = (4186 J)/(3600 s) = 1.16 J/s = 1.16 W

6.8 Other Forms of Energy and the Conservation of Energy

Total mechanical energy is conserved if any nonconservative forces acting do no work ➔ $W_{nc} = 0 = E_f - E_o$ ➔ $E_f = E_o$

Examples of other forms of energy:

Electrical -- electrical currents, lightning bolts….
Chemical -- fuels, explosives……
Heat -- Sun, frictional forces……
Mass -- Relativity (Einstein) ➔ $E = mc^2$ (m = mass, c = speed of light)

THE PRINCIPLE OF CONSERVATION OF ENERGY

Energy can neither be created nor destroyed, but can only be converted from one form to another.