ENERGY

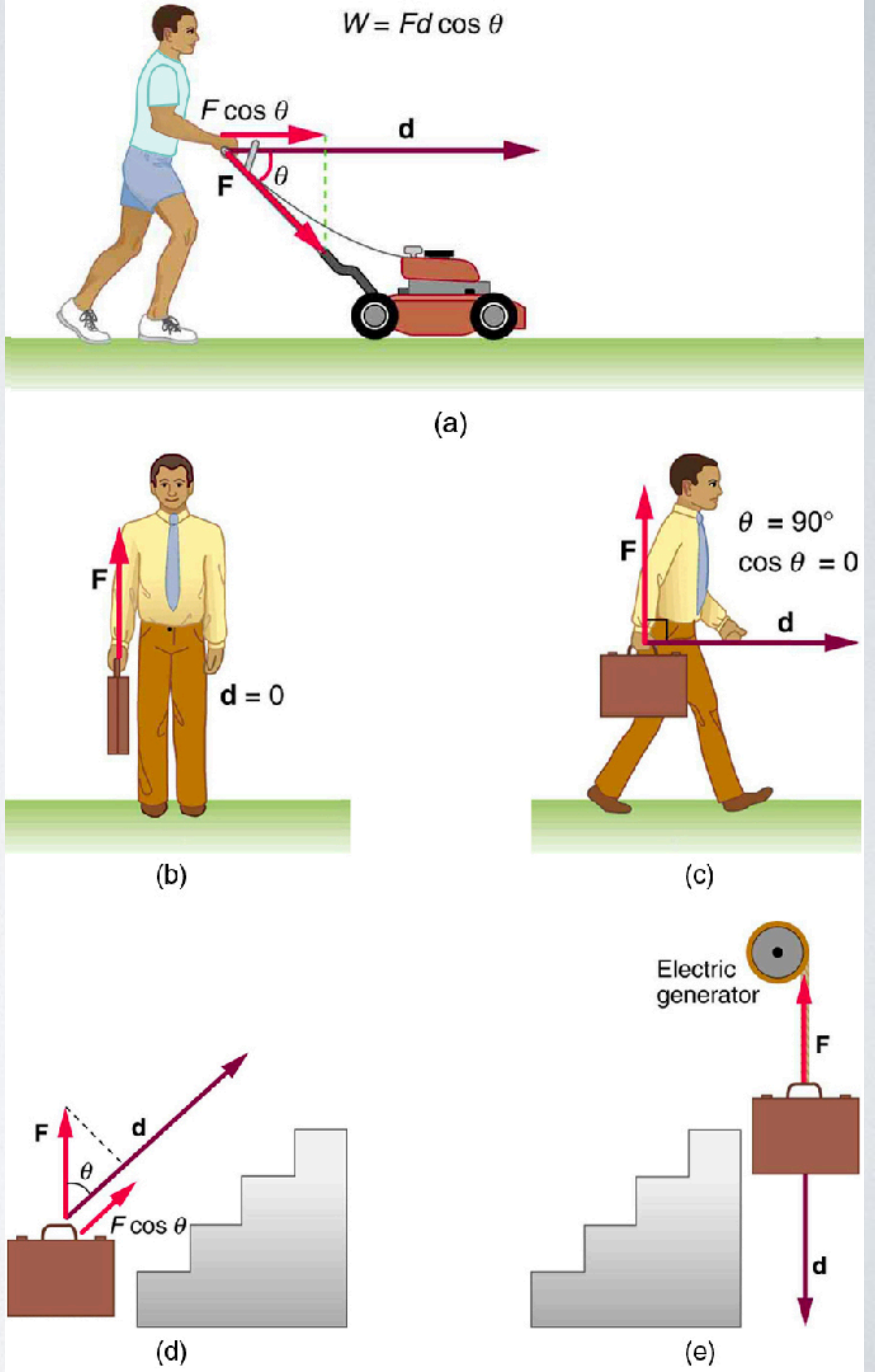
Chapter 7

WORK

- In physics work is the product of force in the direction of motion times the distance the moved. For a constant force

$$W = Fd\cos\theta$$

- The unit of work is the joule (J). A joule is equal to a Newton times a meter, which is a kg m^2/s^2 from the definition of a Newton.



EXAMPLE 7.1

- **Calculating the Work You Do to Push a Lawn Mower Across a Large Lawn**: How much work is done on the lawn mower by the person in the Figure, if he exerts a constant force of 75.0N at an angle 35° below the horizontal and pushes the mower 25.0m on level ground? Convert the amount of work from joules to kilocalories and compare it with this person's average daily intake of 10,000kJ (about 2400kcal) of food energy. One calorie (1 cal) of heat is the amount required to warm 1 g of water by 1°C and is equivalent to 4.186J while one food calorie (1 kcal) is equivalent to 4186J.

F = 75.0 N   W = ?

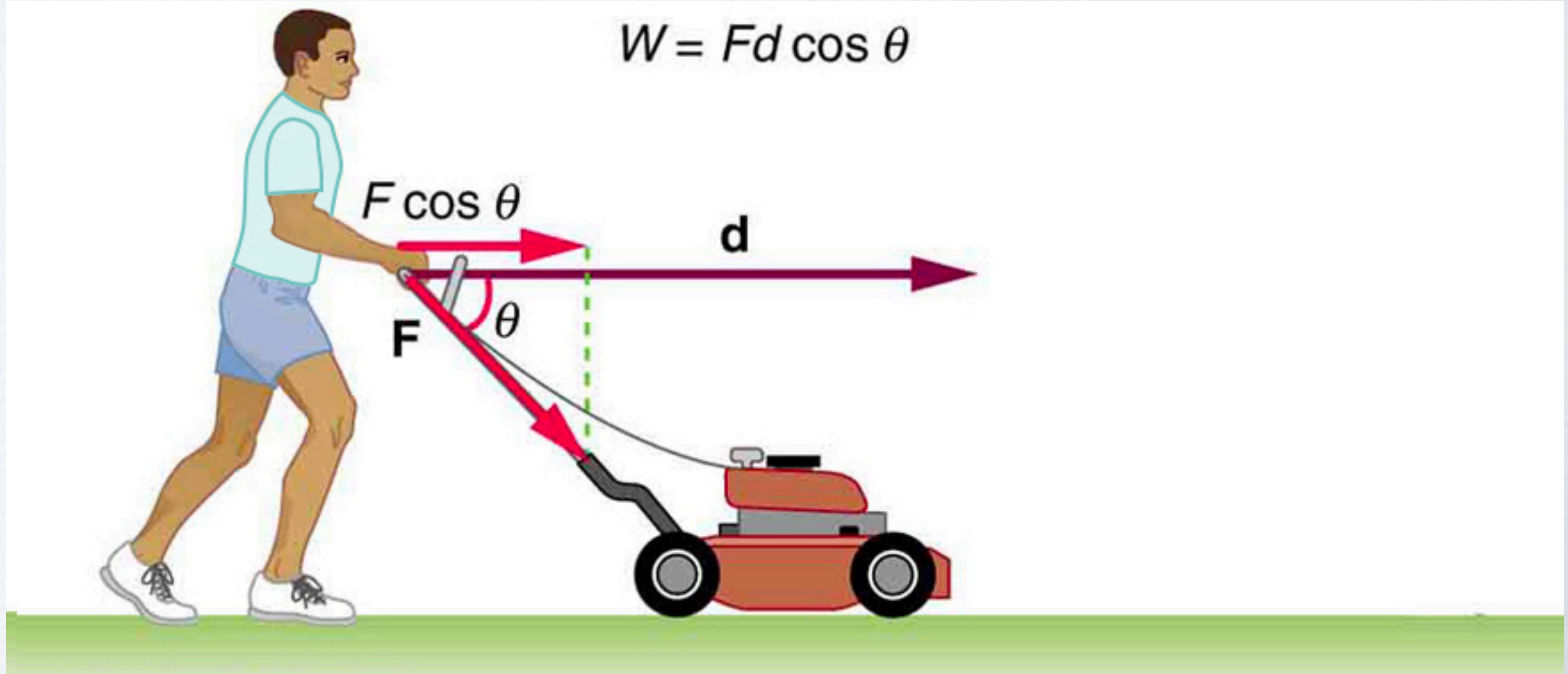
θ = 35

d = 25 m

$$W = Fd\cos\theta = (75N)(25m)\cos 35 = 1536J$$

$$W = 1536J\frac{1kcal}{4186J} = 0.367kcal$$

$$\frac{0.367kcal}{2400kcal} = 1.53 \times 10^{-4}$$



Spiderman 2: Stopping a Train

How much work does Spiderman do stopping the train?

velocity of train = 80mph = 80 (1000m/0.62mi)(1hr/3600s) = 35.8 m/s

distance to stop = 5 blocks? =0.25mi(1000m/0.62mi) ~ 400m

mass of train = 8 cars? = 8 (38,000kg) ~ 300,000kg

assume constant force, which implies constant acceleration

$$v^2 = v_0^2 + 2ax \qquad => a = -\frac{v_0^2}{2x} = -\frac{(35.8m/s)^2}{2(400m)} = 1.6m/s^2$$

$$F = ma = (300,000kg)(1.6m/s^2) = 480,000N$$

this makes spidey super strong,
this is equal to lifting 50,000kg

$$W = Fd = (480,000N)(400m) = 192,000,000\ J$$

a big mac is 2,300kJ, so to make up this energy spidey would have to eat

$$\frac{192,000,000J}{2,300,000J} = 84$$

big macs

WORK ENERGY THEOREM

- What happens when you do work on an object? It gains energy.
- If we apply a constant net force for a distance x we would get

$$W = Fx = max$$

- We know from our constant acceleration formula that

$$v^2 = v_0^2 + 2ax$$

- So we can replace ax in the above formula with

$$W = m(\frac{1}{2}(v^2 - v_0^2)) \qquad W = \frac{1}{2}mv^2 - \frac{1}{2}mv_0^2$$

- we call $1/2mv^2$ kinetic energy (KE)

KINETIC ENERGY

- The energy an object has because it is moving is called kinetic energy.
- It takes work to change an objects kinetic energy.
- Kinetic energy depends on mass and velocity squared, so a 10 times more massive object has 10 times more kinetic energy.
- But an object going 10 times faster has 100 times the energy.

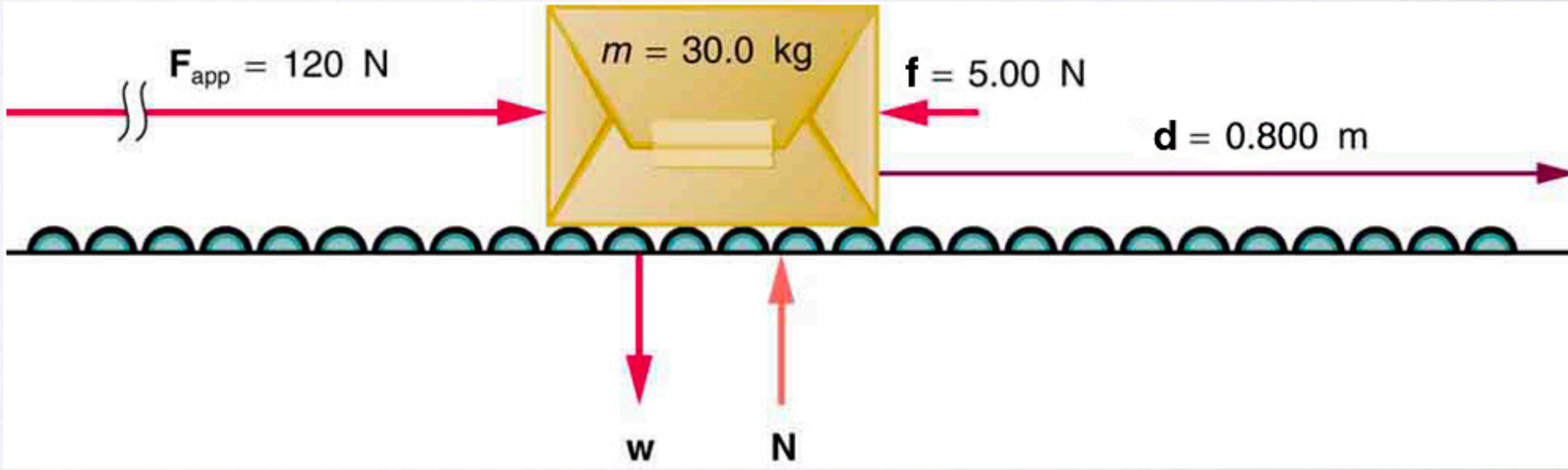
EXAMPLE 7.2

- **Calculating the Kinetic Energy of a Package:** Suppose a 30.0-kg package on the roller belt conveyor system in the Figure is moving at 0.500 m/s. What is its kinetic energy?

m = 30.0 kg   KE = ?

v = 0.500 m/s

$$KE = \frac{1}{2}mv^2 = \frac{1}{2}(30.0kg)(0.500m/s)^2 = 3.75J$$



EXAMPLE 7.3

- **Determining the Work to Accelerate a Package:** Suppose that you push on the 30.0kg package in the Figure with a constant force of 120 N through a distance of 0.800 m, and that the opposing friction force averages 5.00 N. Calculate the net work done on the package.

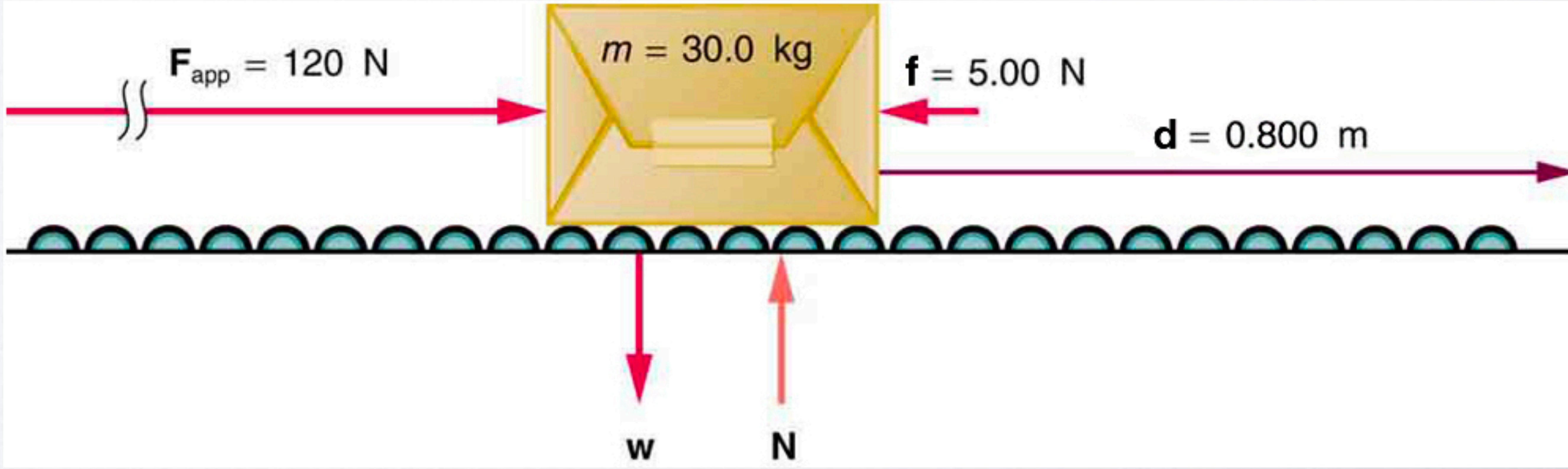
$m = 30.0\ kg$ $W_{net} = ?$

$F_p = 120N$

$d = 0.800m$

$F_{fr} = 5.00N$

$$W_{net} = F_{net}d = (F_p - F_{fr})d = (120N - 5N)0.8m = 92J$$



EXAMPLE 7.4

- **Determining Speed from Work and Energy:** Find the speed of the package in the Figure at the end of the push, using work and energy concepts.

$$W = \frac{1}{2}mv^2 - \frac{1}{2}mv_0^2 \qquad \frac{1}{2}mv^2 = W + KE_0$$

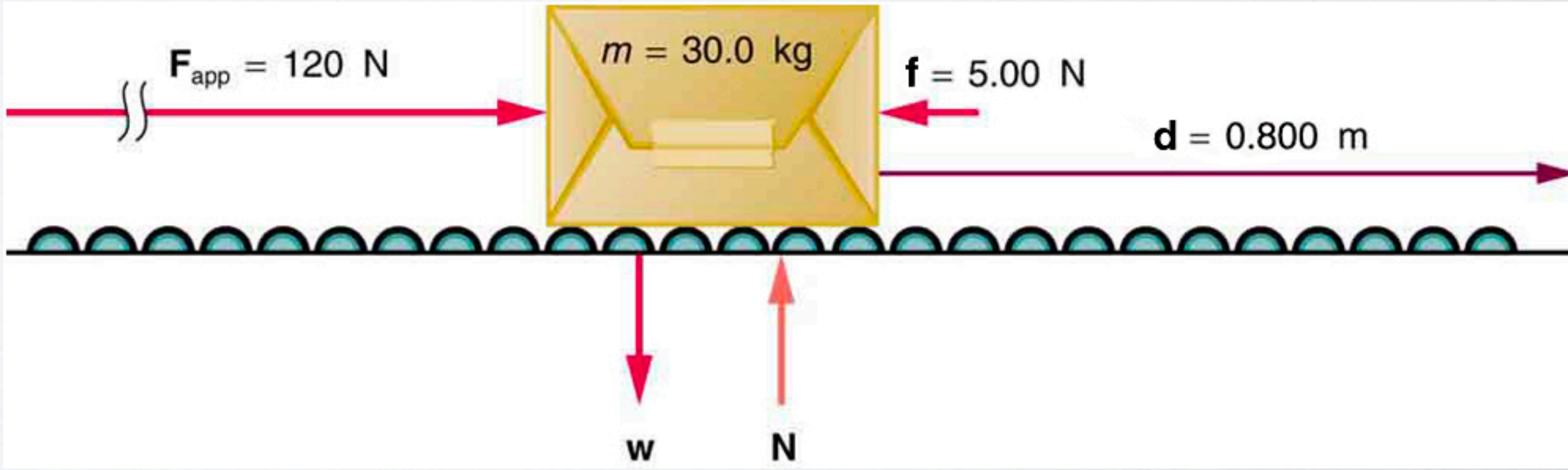
m = 30.0 kg   v = ?

KE_0 = 3.75J

W = 92J

$$v = \sqrt{\frac{2}{m}(W + KE_0)}$$

$$v = \sqrt{\frac{2}{(30.0kg)}(92J + 3.75J)} = 2.53m/s$$



POTENTIAL ENERGY

- What if we do work by lifting a block up in the air? Or throwing a ball into the air? Clearly we have done work, but the block would have no velocity and the ball would reach a point where it has no velocity. Where did the energy go?

- When we do work against a force, we give the object potential energy. The block and ball have zero velocity, but if we let them fall they will gain kinetic energy from their potential energy.

GRAVITATIONAL POTENTIAL ENERGY

- If we lift an object on Earth at zero velocity to a height h then the work we do will be W= Fd = mgh.
- Thus the potential energy gained must be this much. The change in gravitational potential energy is given by

$$\Delta PE_g = mgh$$

SPRING POTENTIAL ENERGY

- Instead let us consider pushing on a spring at constant velocity. The spring force changes from 0 to kx at the maximum compression. The average force will be F_{avg} = 1/2(kx +0) = 1/2kx.

- Applying this average force for the distance x gives us a potential energy

$$\Delta PE_s = \frac{1}{2}kx^2$$

- Every conservative force has an associated potential energy.

GOLDEN EYE (1995)

What is the spring constant of the bungee cord?

This stunt was done for real and the dam used is in Switzerland. You can go today and make the jump yourself. The dam has a height of 220m. At the bottom before Bond shoots his grapple his velocity has slowed to zero. That means his original potential energy has now been entirely converted to the potential energy of the bungee cord which acts just like a spring.

$$mgh = \frac{1}{2}kx^2$$

where x is the distance the bungee cord has stretched. If we assume the bungee cord is 80m long then x = 220m – 80m = 140m where we have neglected the fact that Bond is a couple of meters from the bottom when he shoots his grapple. Note that the bungee cord is stretched to 2.75 times its original length, which is fairly typical for bungee cords. If we take Bonds mass to be 80kg, we then have

$$k = \frac{2mgh}{x^2} = \frac{2(80kg)(9.8m/s^2)(220m)}{(140m)^2} = 17.6N/m$$

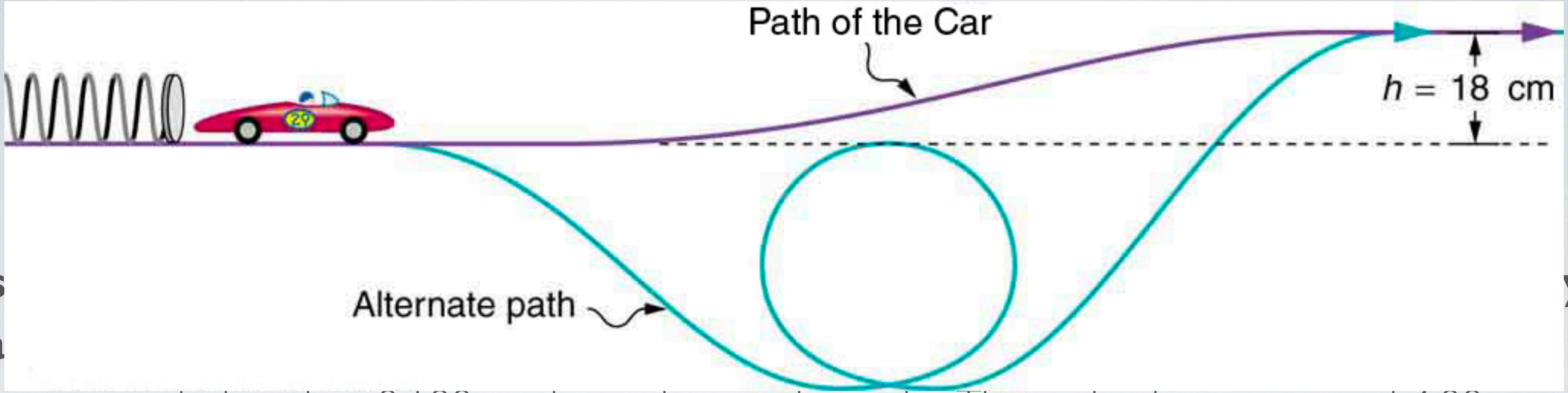
The upward force on Bond when he reaches the bottom is

$$F = kx = (17.6N/m)(140m) = 2,464N$$

This force would give an acceleration of

$$a = F/m = 2464N/80kg = 30.8m/s^2$$

or 3.14g which is also typical in bungee jumping.



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follows a track that rises 0.180 m above the starting point. The spring is compressed 4.00 cm and has a force constant of 250.0 N/m. Assuming work done by friction to be negligible, find (a) how fast the car is going before it starts up the slope and (b) how fast it is going at the top of the slope.

m = 0.100 kg
h = 0.180 m
x = 0.040 m
k = 250.0 N/m

v_1 = ?
v_2 = ?

$$\frac{1}{2}kx^2 = \frac{1}{2}mv_1^2 \qquad v_1 = \sqrt{\frac{k}{m}}\,x \quad = \sqrt{\frac{250N/m}{0.1kg}}(0.04m) = 2.00m/s$$

$$\frac{1}{2}kx^2 = \frac{1}{2}mv_2^2 + mgh$$

$$v_2 = \sqrt{\frac{kx^2}{m} - 2gh} = \sqrt{\frac{(250N/m)(0.04m)^2}{(0.1kg)} - 2(9.8m/s^2)(0.18m)} = 0.687m/s$$

CONSERVATIVE FORCES

- Potential energies don't exist for all forces, a force has to be **conservative** for it to have a potential energy.
- What that means is that when you do work against the force and then let the force push you back to where you started you have to end up unchanged.
- For example a ball bounces up and down against gravity or a mass oscillates up and down on a spring. These are conservative forces.
- However, if you push something back and forth against friction, you do work both ways.
- Friction like forces are not conservative and do not have an associated potential energy. When these forces act they convert mechanical energy to heat which is then lost from the system.

EXAMPLE 7.9

- **Calculating Distance Traveled: How Far a Baseball Player Slides:** Consider the situation shown in Figure 7.16, where a baseball player slides to a stop on level ground. Using energy considerations, calculate the distance the 65.0-kg baseball player slides, given that his initial speed is 6.00 m/s and the force of friction against him is a constant 450 N.

m = 65kg

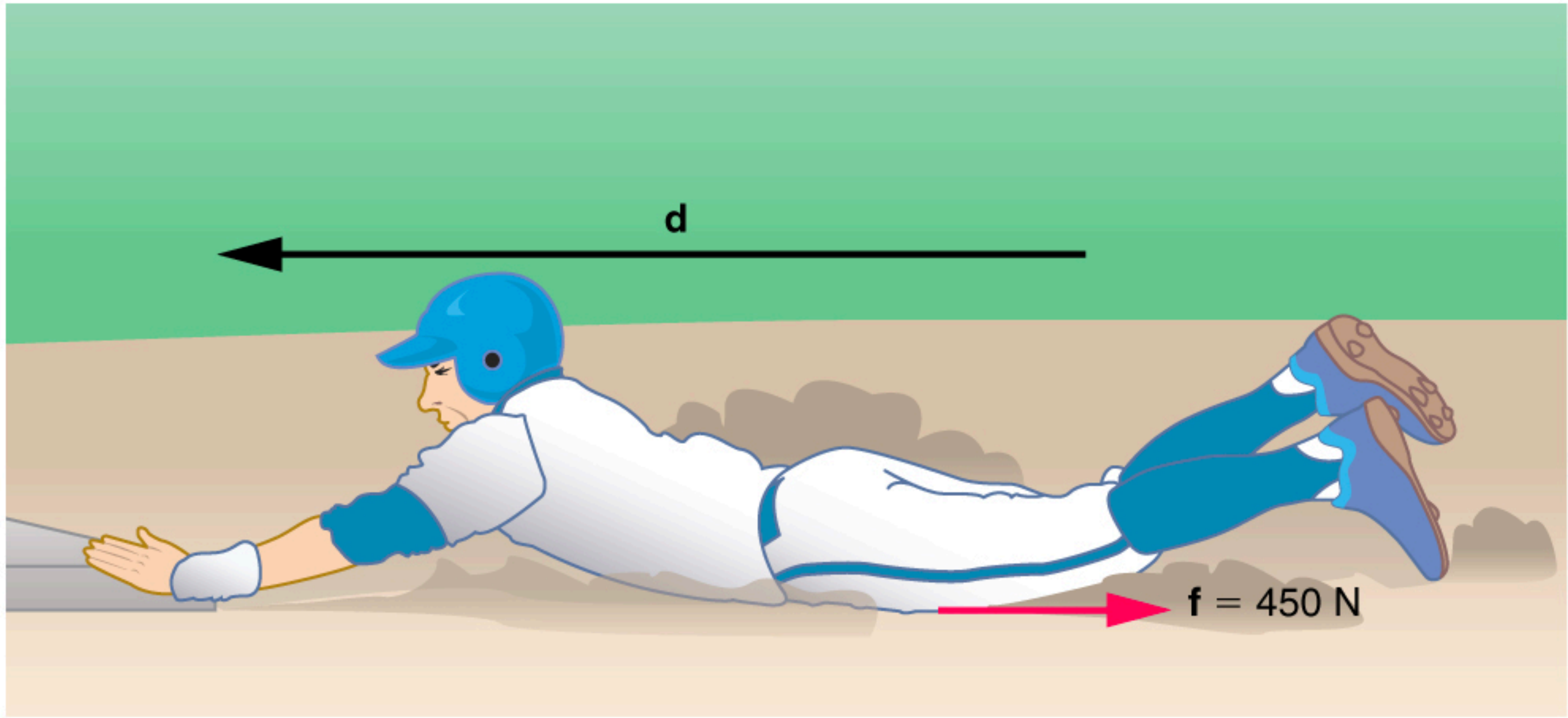
v = 6.00 m/s

f = 450N

d = ?

$$\frac{1}{2}mv^2 = fd$$

$$d = \frac{1}{2}\frac{mv^2}{f} = \frac{1}{2}\frac{(65kg)(6.00m/s)^2}{450N} = 2.6m$$



EXAMPLE 7.10

- **Calculating Distance Traveled: Sliding Up an Incline:** Suppose that the player from Example 7.9 is running up a hill having a 5.00° incline upward with a surface similar to that in the baseball stadium. The player slides with the same initial speed, and the frictional force is still 450 N. Determine how far he slides.

m = 65kg

v = 6.00 m/s

f = 450N

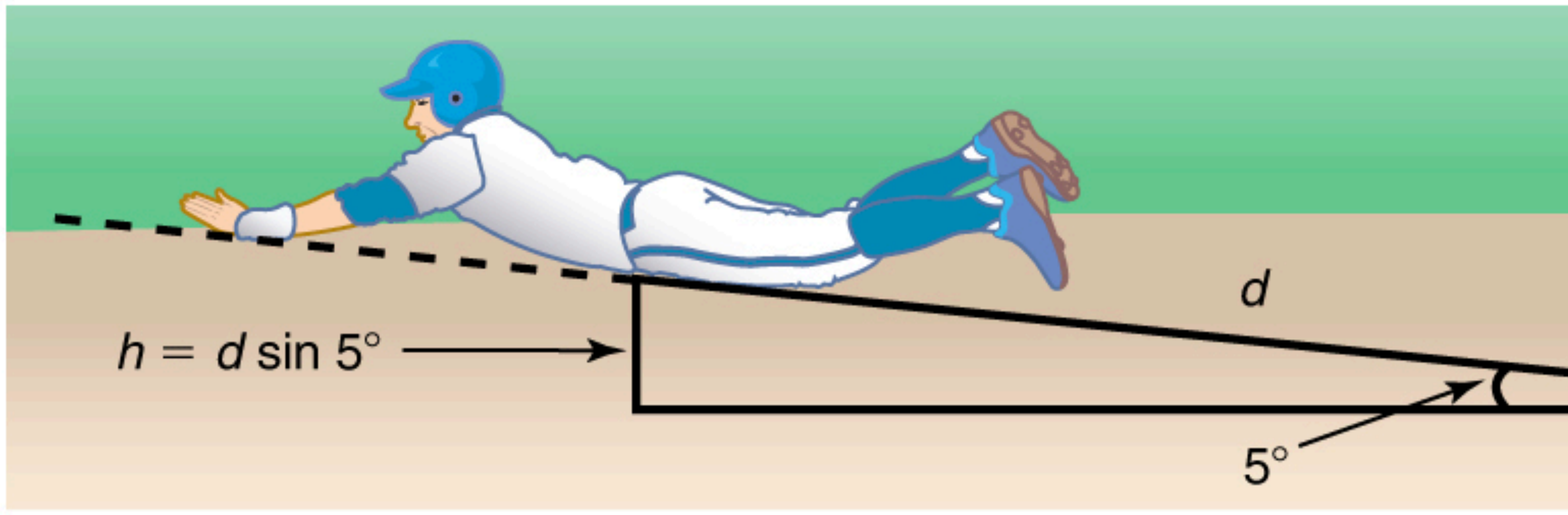
d = ?

$$\frac{1}{2}mv^2 = fd + mgh$$

$$\frac{1}{2}mv^2 = fd + mgd\sin(5)$$

$$d = \frac{\frac{1}{2}mv^2}{f + mg\sin(5)}$$

$$= \frac{\frac{1}{2}(65kg)(6m/s)^2}{450N + (65kg)(9.8m/s^2)\sin(5)} = 2.31m$$



POWER

- Power is the rate of energy use over time. It has units of Watts (W).

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

- Many devices are constricted by the power they require, not the energy they use. With a big enough tank of gas you can drive any distance, but a car will have a maximum velocity it can reach because there is a maximum power the engine can produce.

EXAMPLE 7.11

- **Calculating the Power to Climb Stairs:** What is the power output for a 60.0-kg woman who runs up a 3.00 m high flight of stairs in 3.50 s, starting from rest but having a final speed of 2.00 m/s?

m = 60.0 kg

h = 3.00 m

t = 3.50 s

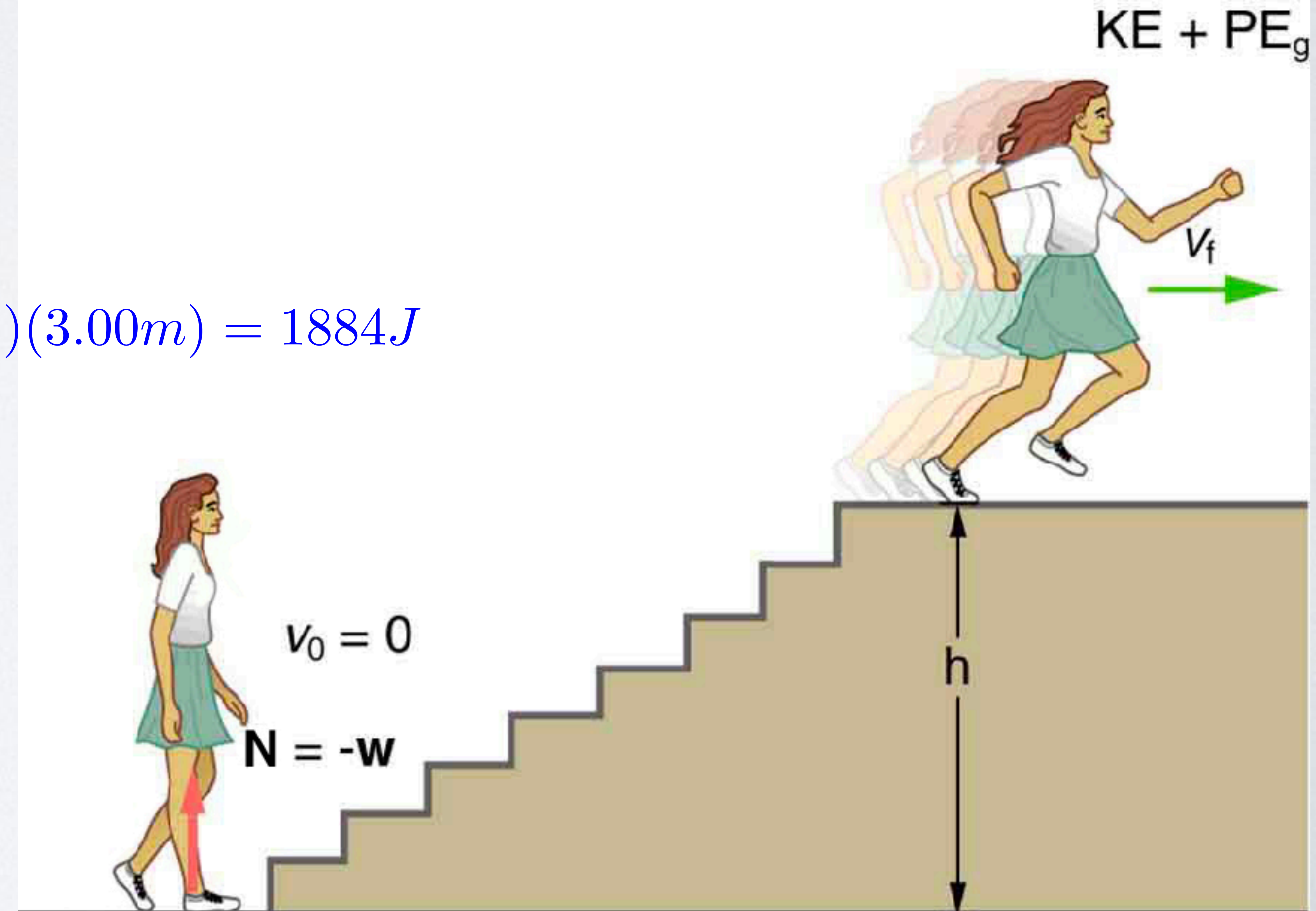
v = 2.00 m/s

P = ?

$$W = \Delta KE + \Delta PE = \frac{1}{2}mv^2 + mgh$$

$$= \frac{1}{2}(60kg)(2m/s)^2 + (60kg)(9.8m/s^2)(3.00m) = 1884J$$

$$P = \frac{W}{t} \quad = \frac{1884J}{3.5s} = 538W$$



HOME WORK

- Chap 7 - 6, 9, 13, 17, 22, 24, 32,