## Chapter 7

7.2 If a Saturn V rocket with an Apollo spacecraft attached has a combined mass of $\mathrm{m}=$ $2.9 \times 10^{5} \mathrm{~kg}$ and is to reach a speed of $\mathrm{v}=11.2 \mathrm{~km} / \mathrm{s}=11.2 \times 10^{3} \mathrm{~m} / \mathrm{s}$, how much Kinetic Energy will it have

$$
K=\frac{1}{2} m v^{2}=1.82 \times 10^{13} \mathrm{~J}
$$

7.3 On August 10, 1972, a large meteorite skipped across the atmosphere above western United States and Canada, much like a stone skipped across water. The accompanying fireball was so bright that it could be seen in the daytime sky. The meteorite's mass was about $4 \times 10^{6} \mathrm{~kg}$; its speed was about $15 \mathrm{~km} / \mathrm{s}$. At it entered the atmosphere vertically, it would have hit the earth's surface with the same speed. (a) Calculate the meteorite's loss of kinetic energy (in joules) that would have been associated with the vertical impact. (b) Express the energy as a multiple of the explosive energy of 1 megaton of TNT, which is $4.2 \times 10^{15} \mathrm{~J}$. (c) The energy associated with the atomic bomb explosion over Hiroshima was equivalent to 13 kilotons of TNT. To how many "Hiroshima bombs" would the meteorite impact have been equivalent?
a. The energy loss would be

$$
\begin{aligned}
K & =\frac{1}{2} m v^{2}=\frac{1}{2} \cdot 4 \times 10^{6} \mathrm{~kg} \cdot(15,000 \mathrm{~m} / \mathrm{s})^{2} \\
& =4.5 \times 10^{14} \mathrm{~J}
\end{aligned}
$$

b. The equivalent loss in megatons of TNT

$$
\# M T=\frac{4.5 \times 10^{14} \mathrm{~J}}{4.2 \times 10^{15} \mathrm{~J} / M T}=0.107 \mathrm{MT}=107 \mathrm{kT}
$$

c How many Hiroshima Bombs is this?

$$
\text { \# Hiroshimas }=\frac{107 k T}{13 k T / \text { Hiroshima }}=8.23
$$

We were very lucky...
7.13 A luge and its rider, with a total mass of 85 kg , emerge from a downhill track onto a horizontal straight track with an initial speed of $37 \mathrm{~m} / \mathrm{s}$. If a force slows them to a stop at a constant rated of $2.0 \mathrm{~m} / \mathrm{s}^{2}$, (a) what magnitude F is required for the force, (b)what distance d do they travel while slowing and (c) what work W is done on them by the force? What are (d) F, (e) d and (f) W if they instead slow at $4 \mathrm{~m} / \mathrm{s}^{2}$.

We can easily compute the magnitude of the force.

$$
F=m a=85 \mathrm{~kg} \cdot 2 \mathrm{~m} / \mathrm{s}^{2}=170 \mathrm{~N}
$$

It's easier to compute the work done next. The work done is just the change in the KE.

$$
\Delta K E=0-\frac{1}{2} m v_{i}^{2}=-58,182.5 \mathrm{~J}
$$

Now that we know the work done, we can compute the distance

$$
\begin{aligned}
& W=\vec{F} \cdot \vec{d} \\
& -58182.5 \mathrm{~J}=-170 \cdot d \\
& d=342.25 \mathrm{~m}
\end{aligned}
$$

If the acceleration is $4 \mathrm{~m} / \mathrm{s}^{2}$, The force doubles to 340 N , the d drops by a factor of 2 to 171.125 m , and the work remains the same (since the change in the KE is the same)
7.15 Figure 7-27 shows three forces applied to a trunk that moves leftward by 3 m over a a frictionless floor. The force magnitudes are $F_{1}=5.00 \mathrm{~N}, F_{2}=9.00 \mathrm{~N}$, and $\mathrm{F}_{3}=3.00 \mathrm{~N}$. During the displacement, (a) what is the net work done on the trunk by the three forces and (b) does the kinetic energy of the trunk increase or decrease?

Since there is no motion in the vertical direction, there is no work done by forces and components of forces in that direction. We need only concern ourselves with the horizontal motion

$$
\begin{aligned}
F_{n e t-x} & =F_{2} \cos 60-F_{1} \\
& =9.00 \mathrm{~N} \cdot \cos 60-5.00 \mathrm{~N} \\
& =-0.5 \mathrm{~N}
\end{aligned}
$$

The net force is to the left. This is in the same direction as the motion. The work done is therefore positive.

$$
\begin{aligned}
W & =F_{n e t-x} d \\
& =0.5 \mathrm{~N} \cdot 3 \mathrm{~m} \\
& =1.5 \mathrm{~J}
\end{aligned}
$$

The work done on the trunk is positive, so the kinetic energy increases.
7.17 A helicopter lifts a 72 kg astronaut 15 m vertically from the ocean by means of a cable. The acceleration of the astronaut is $g / 10$. How much work is done on the astronaut by (a) the
force from the helicopter and (b) the gravitational force on her. Just before she reaches the helicopter, what are her (c)kinetic energy and (d) speed?

Two forces act on the astronaut, as shown below. To find the work done, we need to find the tension. We can then find the work done by the tension T, the weight, and the net work done.


$$
\begin{aligned}
& W_{T}=T d=776.16 \mathrm{~N} \cdot 15 \mathrm{~m}=11,642.4 \mathrm{~J} \\
& W_{m g}=-m g d=-10,584.0 \mathrm{~J} \\
& W_{\text {net }}=W_{T}+W_{m g}=1058.4 \mathrm{~J}
\end{aligned}
$$

Now that we have the net work, we can find the final KE and velocity

$$
\begin{aligned}
& K E_{f}-K E_{i}=W_{\text {net }} \\
& K E_{f}-0 J=W_{\text {net }} \\
& K E_{f}=W_{\text {net }}=1058.4 \mathrm{~J} \\
& \frac{1}{2} m v_{f}^{2}=W_{\text {net }} \\
& v_{f}=\sqrt{\frac{2 W_{\text {net }}}{m}}=5.42 \mathrm{~m} / \mathrm{s}
\end{aligned}
$$

7.22 A cave rescue team lifts an injured spelunker directly upward and out of a sinkhole by means of a motor driven cable. The lift is performed in three stages, each requiring a vertical distance of 10.0 m : (a) initially stationary spelunker is accelerated to a speed of $5.00 \mathrm{~m} / \mathrm{s}$; (b) he is then lifted at the constant speed of $5.00 \mathrm{~m} / \mathrm{s}$; (c) finally he is decelerated to zero speed. How much work is done on the 80 kg rescuee by the force lifting him during each stage.

Two forces act on the rescuee: Tension in the cable and weight.


We are interested in finding the work done by the tension. We will do this by calculating the net work done first.

Stage I. (final velocity $=5 \mathrm{~m} / \mathrm{s}$, initial velocity $=0 \mathrm{~m} / \mathrm{s}$ )

$$
\begin{aligned}
& W_{\text {net }}=\Delta K E=\frac{1}{2} m v_{f}^{2}-0=1000 \mathrm{~J} \\
& W_{m g}=-m g d=-80 \mathrm{~kg} \cdot 9.8 \frac{\mathrm{~m}}{\mathrm{~s}^{2}} \cdot 10 \mathrm{~m}=-7840 \mathrm{~J} \\
& W_{\text {net }}=W_{m g}+W_{T} \\
& W_{T}=W_{\text {net }}-W_{m g}=1000 \mathrm{~J}-(-7840 \mathrm{~J})=8840 \mathrm{~J}
\end{aligned}
$$

Stage II (final velocity $=5 \mathrm{~m} / \mathrm{s}$, initial velocity $=5 \mathrm{~m} / \mathrm{s}$ )

$$
\begin{aligned}
& W_{\text {net }}=\Delta K E=\frac{1}{2} m v_{f}^{2}-\frac{1}{2} m v_{i}^{2}=0 \mathrm{~J} \\
& W_{m g}=-m g d=-80 \mathrm{~kg} \cdot 9.8 \frac{\mathrm{~m}}{\mathrm{~s}^{2}} \cdot 10 \mathrm{~m}=-7840 \mathrm{~J} \\
& W_{\text {net }}=W_{m g}+W_{T} \\
& W_{T}=W_{\text {net }}-W_{m g}=0 \mathrm{~J}-(-7840 \mathrm{~J})=7840 \mathrm{~J}
\end{aligned}
$$

Stage II (final velocity $=5 \mathrm{~m} / \mathrm{s}$, initial velocity $=5 \mathrm{~m} / \mathrm{s}$ )

$$
\begin{aligned}
& W_{\text {net }}=\Delta K E=\frac{1}{2} m v_{f}^{2}-\frac{1}{2} m v_{i}^{2}=0 \mathrm{~J} \\
& W_{m g}=-m g d=-80 \mathrm{~kg} \cdot 9.8 \frac{\mathrm{~m}}{\mathrm{~s}^{2}} \cdot 10 \mathrm{~m}=-7840 \mathrm{~J} \\
& W_{\text {net }}=W_{m g}+W_{T} \\
& W_{T}=W_{\text {net }}-W_{m g}=0 \mathrm{~J}-(-7840 \mathrm{~J})=7840 \mathrm{~J}
\end{aligned}
$$

Stage III (final velocity $=0 \mathrm{~m} / \mathrm{s}$, initial velocity $=5 \mathrm{~m} / \mathrm{s}$ )

$$
\begin{aligned}
& W_{\text {net }}=\Delta K E=\frac{1}{2} m v_{f}^{2}-\frac{1}{2} m v_{i}^{2}=0 \mathrm{~J}-1000 \mathrm{~J} \\
& W_{m g}=-m g d=-80 \mathrm{~kg} \cdot 9.8 \frac{\mathrm{~m}}{\mathrm{~s}^{2}} \cdot 10 \mathrm{~m}=-7840 \mathrm{~J} \\
& W_{\text {net }}=W_{m g}+W_{T} \\
& W_{T}=W_{\text {net }}-W_{m g}=-1000 \mathrm{~J}-(-7840 \mathrm{~J})=6840 \mathrm{~J}
\end{aligned}
$$

7.28 During spring semester at MIT, residents of the parallel buildings of the East Campus dorms battle one another with large catapults that are made with surgical hose mounted on a window frame. A balloon filled with dyed water is placed in a pouch attached to the hose, which is stretched through the width of the room. Assume that the stretching of the hose obeys Hooke's law with a spring constant of $100 \mathrm{~N} / \mathrm{m}$. If the hose is stretched by 5.00 m and then released, how much work does the force from the hose do on the balloon in the pouched by the time the hose reaches its relaxed length.

The magnitude of the work is

$$
W=\frac{1}{2} k x^{2}=\frac{1}{2} \cdot 100 \mathrm{~N} / \mathrm{m} \cdot(5.00 \mathrm{~m})^{2}=1250 \mathrm{~J}
$$

The work done is positive because the force acts in the direction of the motion.
7.39 Figure $7-41$ gives the acceleration of a 2.00 kg particle as an applied force $\vec{F}_{a}$ moves it from rest long an x axis form $\mathrm{x}=0$ to $\mathrm{x}=9 \mathrm{~m}$. The scale of the figure's vertical axis is set by $a_{s}=6 \mathrm{~m} / \mathrm{s}^{2}$. How much work has the force done on the particle when the particle reaches (a) $x=4.0 \mathrm{~m}$, (b) $x=7.0 \mathrm{~m}$, (c) $x=9.0 \mathrm{~m}$ ? What is the particle's speed and direction of travel when it reaches (d) $x=4.0 \mathrm{~m}$, (e) $x=7.0 \mathrm{~m}$, and (f) $x=9.0 \mathrm{~m}$ ?

We can convert the graph of acceleration to the graph of force just by multiplying by the mass. The graph becomes


We calculate by finding the areas under the curve.

$$
\begin{aligned}
& W_{0-4}=\frac{1}{2} \cdot 1 \cdot 12+3 \cdot 12=42 \mathrm{~J} \\
& W_{0-7}=\frac{1}{2} \cdot 1 \cdot 12+3 \cdot 12+\frac{1}{2} \cdot 1 \cdot 12+\frac{1}{2} \cdot 1 \cdot-12+1 \cdot-12=30 \mathrm{~J} \\
& W_{0-9}=\frac{1}{2} \cdot 1 \cdot 12+3 \cdot 12+\frac{1}{2} \cdot 1 \cdot 12+\frac{1}{2} \cdot 1 \cdot-12+2 \cdot-12+\frac{1}{2} \cdot 1 \cdot-12=12 \mathrm{~J}
\end{aligned}
$$

We can find the speed from

$$
\begin{aligned}
W & =\Delta K=K_{f}-K_{i} & v_{4} & =\sqrt{\frac{2 W_{0-4}}{m}}=\sqrt{\frac{2 \cdot 42 J}{2 k g}}=6.48 \mathrm{~m} / \mathrm{s} \\
& =\frac{1}{2} m v_{f}^{2}-\frac{1}{2} m v_{i}^{2} & v_{7} & =\sqrt{\frac{2 W_{0-7}}{m}}=\sqrt{\frac{2 \cdot 30 J}{2 k g}}=5.5 \mathrm{~m} / \mathrm{s} \\
& =\frac{1}{2} m v_{f}^{2}-0 & v_{7} & =\sqrt{\frac{2 W_{0-9}}{m}}=\sqrt{\frac{2 \cdot 12 J}{2 k g}}=3.46 \mathrm{~m} / \mathrm{s}
\end{aligned}
$$

The motion is in the positive direction in all of these cases.
7.44 A skier is pulled by a towrope up a frictionless ski slop that makes an angle of 12 degrees with the horizontal. The rope moves parallel to the slope with a constant speed of $1.0 \mathrm{~m} / \mathrm{s}$. The rope of the rope does 900 J of work on the skier as the skier moves a distance 8.0 m up the incline. (a) If the rope moved with a constant speed of $2 \mathrm{~m} / \mathrm{s}$, how much work would the force of the rope do on the skier as the skier moved a distance of 8.0 m up the incline. At what rate is the force of the rope doing work on the skier when the rope moves with a speed of (b) $1.0 \mathrm{~m} / \mathrm{s}$ and (c) $2.0 \mathrm{~m} / \mathrm{s}$
(a) This is a bit of an odd question. If we assume that the force in part a is the same, the work is the same, since the distance is unchanged and work only depends on force and distance.

The power IS different. The force doing the work is

$$
F=\frac{900 \mathrm{~J}}{8 m}=112.5 \mathrm{~N}
$$

The power at $1.0 \mathrm{~m} / \mathrm{s}$ is

$$
P=\vec{F} \cdot \vec{v}=112.5 \mathrm{~N} \cdot 1 \mathrm{~m} / \mathrm{s}=112.5 \mathrm{~W}
$$

and at $2.0 \mathrm{~m} / \mathrm{s}$ is

$$
P=\vec{F} \cdot \vec{v}=112.5 \mathrm{~N} \cdot 2 \mathrm{~m} / \mathrm{s}=225 \mathrm{~W}
$$

7.62 A 250 g block is dropped onto a vertical spring with spring constant $\mathrm{k}=2.5 \mathrm{~N} / \mathrm{cm}$. the block becomes attached to the spring and the spring compresses 12 cm before momentarily stopping. While the spring is being compressed, what work is done on the block (a) by its weight, and (b) by the spring force? (c) What is the speed of the block just before it hits the spring? (d) If the speed is doubled,what is the maximum compression of the spring.
a. The work done by weight is positive. The force is downward and so is the motion.

$$
\begin{aligned}
W_{w} & =m g y=0.25 \mathrm{~kg} \cdot 9.8 \mathrm{~m} / \mathrm{s}^{2} \cdot 0.12 \mathrm{~m} \\
& =0.294 \mathrm{~J}
\end{aligned}
$$

b) The work done by the spring is negative. The force is upward but the motion is downward.

$$
\begin{aligned}
k & =\frac{2.5 \mathrm{~N}}{c m} \cdot \frac{100 \mathrm{~cm}}{1 \mathrm{~m}}=250 \mathrm{~N} / \mathrm{m} \\
W_{s} & =-\frac{1}{2} k x^{2}=-\frac{1}{2} \cdot 250 \mathrm{~N} / \mathrm{m} \cdot(0.12 \mathrm{~m})^{2} \\
& =-1.8 \mathrm{~J}
\end{aligned}
$$

c) The net work done equals the change in Kinetic energy.

$$
\begin{aligned}
& W_{\text {net }}=W_{m g}+W_{s}=0.294 \mathrm{~J}-1.8 \mathrm{~J}=-1.506 \mathrm{~J} \\
& K_{f}-K_{i}=W_{\text {net }} \\
& 0-\frac{1}{2} m v_{i}^{2}=W_{\text {net }} \\
& v_{i}=\sqrt{\frac{-2 W_{\text {net }}}{m}}=\sqrt{\frac{-2 \cdot(-1.506 \mathrm{~J})}{0.25}}=3.47 \mathrm{~m} / \mathrm{s}
\end{aligned}
$$

d) Use work to determine the final compression. The velocity is twice the value found in part c . We choose the negative solution, since we know that the mass drops below the zero starting value...

$$
\begin{aligned}
& v_{i}=2 \cdot 3.47 m / s=6.94 m / s \\
& W_{\text {net }}=\Delta K=0-\frac{1}{2} m v_{i}^{2} \\
& W_{\text {net }}=m g y-\frac{1}{2} k y^{2} \\
& m g y-\frac{1}{2} k y^{2}=-\frac{1}{2} m v_{i}^{2} \\
& \frac{1}{2} k y^{2}-m g y-\frac{1}{2} m v_{i}^{2}=0 \\
& y=\frac{+m g \pm \sqrt{(m g)^{2}-4 \cdot \frac{1}{2} k \cdot\left(-\frac{1}{2} m v_{i}^{2}\right)}}{2 \cdot\left(\frac{1}{2} k\right)} \\
& =\frac{+m g \pm \sqrt{\left.(m g)^{2}+k m v_{i}^{2}\right)}}{k} \\
& =\frac{+0.25 \mathrm{~kg} \cdot 9.8 m / s^{2} \pm \sqrt{\left(0.25 \mathrm{~kg} \cdot 9.8 m / \mathrm{s}^{2}\right)^{2}+250 \mathrm{~N} / \mathrm{m} \cdot 0.25 \mathrm{~kg} \cdot(6.94 \mathrm{~m} / \mathrm{s})^{2}}}{250 \mathrm{~N} / \mathrm{m}} \\
& =-0.2099 m
\end{aligned}
$$

