6.5

Use Eq. (6.3): $W = Fs\cos\theta$. Here both the force and the displacement are horizontal so $\theta = 0$. Thus

$$W = Fs\cos\theta = (15\,\mathrm{N})(1.5\,\mathrm{m})(\cos 0) = 23\,\mathrm{J}\,,$$

which is done in overcoming friction.

6.11

Solve for the average force F from Eq. (6.3): $F = W/s\cos\theta$. In this case $W = 400\,\mathrm{J}$, $s = 100\,\mathrm{m}$, and $\theta = 0$; so

$$F = \frac{W}{s\cos\theta} = \frac{400\,\mathrm{J}}{100\,\mathrm{m}(\cos 0)} = 4.00\,\mathrm{N}\,.$$

6.13

In the first 90 s of flight the thrust F is constant at $10 \times 10^3\,\mathrm{N} = 10^4\,\mathrm{N}$, as you can see in Fig. P13. Hence

$$W = Fh = (10^4\,\mathrm{N})(2.0 \times 10^3\,\mathrm{m}) = 2.0 \times 10^7\,\mathrm{J} = 20\,\mathrm{MJ}\,.$$

6.25

The weight of the object is being supported by five segments of rope, as shown in Fig. P25. Each segment supports 1/5 of the weight. The force that is needed to pull out the rope, being equal to the tension in the rope, is therefore only 1/5 of the weight to be raised. Since work-in = work-out, in order to raise the weight by 1.0 m we need to pull out $5 \times 1.0\,\mathrm{m} = 5.0\,\mathrm{m}$ of the rope.

6.26

The direction of $\vec{\mathbf{F}}$, the force pulling the barge, makes an angle of $\theta = 30°$ with the direction of motion of the barge. So the work done against friction is

$$W = Fs\cos\theta = (1000\,\mathrm{N})(10 \times 10^3\,\mathrm{m})(\cos 30°) = 8.7 \times 10^6\,\mathrm{J} = 8.7\,\mathrm{MJ}\,.$$

6.30

Let the total weight of the crates plus the wagon be F_w. In order to push the load up an incline, a force $F = F_\mathrm{w}\sin\theta$ needs to be applied on the load to overcome gravity. Here θ is the angle of inclination. The work done by F as the load is pushed up the incline by a distance s is then $W = Fs = F_\mathrm{w}s\sin\theta$. With $F_\mathrm{w} = 400\,\mathrm{N} + (10.0\,\mathrm{kg})(9.81\,\mathrm{m/s^2}) = 498.1\,\mathrm{N}$, $s = 10.0\,\mathrm{m}$, and $\theta = 30.0°$,

$$W = F_\mathrm{w}s\sin\theta = (498.1\,\mathrm{N})(10.0\,\mathrm{m})(\sin 30.0°) = 2.49\,\mathrm{kJ}\,.$$

6.34

Let the mass of each book be m and its thickness be h. Then the work done against gravity in stacking the second book atop the first one is $W_1 = F_\mathrm{w}h = mgh$. Next, to stack the third book atop the second one we need to lift the third book by $2h$, which requires a work of $W_2 = 2mgh$. Similarly, to stack the remaining two books require a work of $W_3 = 3mgh$ and $W_4 = 4mgh$, respectively. The total work needed is then

$$W = \sum_{i=1}^{4} W_i = mgh(1+2+3+4) = 10(2.5\,\mathrm{kg})(9.81\,\mathrm{m/s^2})(0.10\,\mathrm{m}) = 25\,\mathrm{J}\,.$$

Initially, the center-of-mass of the books is at the middle of each book, or $\frac{1}{2}(10\,\text{cm}) = 5.0\,\text{cm}$ above the table top. After the stacking process the new center-of-mass is at the middle of the third book, or $2.5h = 2.5(10\,\text{cm}) = 25\,\text{cm}$ above the table top. Thus the center-of-mass rises by $\Delta h_{\text{cm}} = 25\,\text{cm} - 5.0\,\text{cm} = 20\,\text{cm}$. In fact we can also obtain W from

$$W = m_{\text{total}} g \Delta h_{\text{cm}} = (5 \times 2.5\,\text{kg})(9.81\,\text{m/s}^2)(20\,\text{cm}) = 25\,\text{J}\,.$$

6.36

The energy expended is equal to work-in, and the corresponding work-out is the work done against gravity: work-out $= mg\Delta h$, where $m = 60\,\text{kg}$ and $\Delta h = 25\,\text{m}$. Hence $e =$ work-out/work-in $= mg\Delta h/$work-in $= 20\%$, which gives

$$\text{work-in} = \frac{mg\Delta h}{e} = \frac{(60\,\text{kg})(9.81\,\text{m/s}^2)(25\,\text{m})}{20\%} = 7.4 \times 10^4\,\text{J}\,.$$

6.48

Set up an xy coordinate system, with the x- and z-axes pointing horizontally and the y-axis vertically upward. Since the force $\vec{\mathbf{F}}$ is straight up, $\vec{\mathbf{F}} = F\,\hat{\mathbf{j}}$. Suppose that the object moves by an arbitrary, infinitesimal displacement $d\vec{s} = (dx)\,\hat{\mathbf{i}} + (dy)\,\hat{\mathbf{j}} + (dz)\,\hat{\mathbf{k}}$ under the influence of $\vec{\mathbf{F}}$, then according to the definition the work dW done by $\vec{\mathbf{F}}$ over the displacement $d\vec{s}$ is

$$\begin{aligned} dW &= \vec{\mathbf{F}}\cdot d\vec{s} \\ &= F\,\hat{\mathbf{j}}\cdot[(dx)\,\hat{\mathbf{i}} + (dy)\,\hat{\mathbf{j}} + (dz)\,\hat{\mathbf{k}}] \\ &= F dx(\hat{\mathbf{j}}\cdot\hat{\mathbf{i}}) + F dy(\hat{\mathbf{j}}\cdot\hat{\mathbf{j}}) + F dz(\hat{\mathbf{j}}\cdot\hat{\mathbf{k}}) \\ &= F dy\,, \end{aligned}$$

where we noted that $\hat{\mathbf{j}}\cdot\hat{\mathbf{i}} = \hat{\mathbf{j}}\cdot\hat{\mathbf{k}} = 0$ and $\hat{\mathbf{j}}\cdot\hat{\mathbf{j}} = 1$. Integrating from the initial to the final point, we get

$$W_{P_i \to P_f} = \int_{P_i}^{P_f} dW = \int_{y_i}^{y_f} F\,dy = F\int_{y_i}^{y_f} dy = F(y_f - y_i)\,,$$

which indeed depends only on $\Delta y = y_f - y_i$, the change in height.

6.54

Use Eq. (6.13), with $m = 1.0\,\text{g} = 1.0 \times 10^{-3}\,\text{kg}$ and $v = 70\,\text{km/s} = 70 \times 10^3\,\text{m/s}$:

$$\text{KE} = \frac{1}{2}mv^2 = \frac{1}{2}(1.0 \times 10^{-3}\,\text{kg})(70 \times 10^3\,\text{m/s})^2 = 2.5 \times 10^6\,\text{J} = 2.5\,\text{MJ}\,.$$

6.57

Use Eq. (6.13), with $m = 6.5\,\text{g} = 6.5 \times 10^{-3}\,\text{kg}$ and $v = 300\,\text{m/s}$:

$$\text{KE} = \frac{1}{2}mv^2 = \frac{1}{2}(6.5 \times 10^{-3}\,\text{kg})(300\,\text{m/s})^2 = 2.9 \times 10^2\,\text{J} = 0.29\,\text{kJ}\,.$$

6.65

By definition $\text{KE} = \frac{1}{2}mv^2$. For the shot (S)

$$\text{KE}_S = \frac{1}{2}m_S v_S^2 = \frac{1}{2}(7.26\,\text{kg})(14\,\text{m/s})^2 = 7.1 \times 10^2\,\text{J} = 0.71\,\text{kJ}\,;$$

and for the baseball (B)

$$\text{KE}_B = \frac{1}{2}m_B v_B^2 = \frac{1}{2}(0.149\,\text{kg})(45\,\text{m/s})^2 = 1.5 \times 10^2\,\text{J} = 0.15\,\text{kJ}\,.$$

The energy expended by the athlete goes partly into the kinetic energy of the shot or the ball, while the rest ends up mostly as thermal energy in his body. The shot is considerably more massive and can carry with it more kinetic energy.

6.79

The increase in gravitational potential energy of a load of mass m as it ascends by a vertical displacement h is $\Delta\text{PE}_G = mgh$. This comes from the chemical energy $\text{PE}_C = 6 \times 10^9\,\text{J}$. Let $\Delta\text{PE}_G = mgh = \text{PE}_C$ and solve for h:

$$h = \frac{\text{PE}_C}{mg} = \frac{6 \times 10^9\,\text{J}}{(1 \times 10^6\,\text{kg})(9.8\,\text{m/s}^2)} = 6 \times 10^2\,\text{m}\,.$$

6.88

(a) With an acceleration of $a = 2.00\,\text{m/s}^2$, the speed v of the package at time t is given by $v = at$. At $t = 10.0\,\text{s}$, $v = (2.00\,\text{m/s}^2)(10.0\,\text{s}) = 20.0\,\text{m/s}$; so its KE at that time is

$$\text{KE} = \frac{1}{2}mv^2 = \frac{1}{2}(10.0\,\text{kg})(20.0\,\text{m/s})^2 = 2.00 \times 10^3\,\text{J} = 2.00\,\text{kJ}\,.$$

(b) The vertical displacement of the package from $t = 0$ to $t = 10.0\,\text{s}$ is $\Delta h = \frac{1}{2}at^2 = \frac{1}{2}(2.00\,\text{m/s}^2)(10.0\,\text{s})^2 = 100\,\text{m}$. The change in *gravitational*-PE is then

$$\Delta\text{PE}_G = mg\Delta h = (10.0\,\text{kg})(9.81\,\text{m/s}^2)(100\,\text{m}) = 9.81 \times 10^3\,\text{J} = 9.81\,\text{kJ}\,.$$

(c) The work W_E done by the elevator is equal to the increase in the mechanical energy of the package:

$$W_E = \Delta\text{KE} + \Delta\text{PE}_G = 2.00\,\text{kJ} + 9.81\,\text{kJ} = 11.81\,\text{kJ}\,.$$

6.101

Consider one of the two cars, which has a mass m and is moving at an initial speed v_i towards the hill. Its kinetic energy before climbing the hill is $KE_i = \frac{1}{2}mv_i^2$. Suppose that the greatest height of a hill the car can successfully climb is h_{max} provided that the car does not lose any energy to friction. Then the car can barely make it to the top of such a hill, meaning that by the time it does so it must have no KE left, i.e. all of its initial KE has been converted to its final *gravitational*-PE. Thus $KE_i = \frac{1}{2}mv_i^2 = PE_{Gf} = mgh_{max}$, which gives the maximum height h_{max} of the hill it can climb to be

$$h_{max} = \frac{v_i^2}{2g}.$$

Note that this result is *independent* of the mass m of the car. In our case, with $v_i = (96\,\mathrm{km/h})(10^3\,\mathrm{m/km})(1\,\mathrm{h}/3600\,\mathrm{s}) = 26.7\,\mathrm{m/s}$, the maximum scalable height is

$$h_{max} = \frac{(26.7\,\mathrm{m/s})^2}{2(9.81\,\mathrm{m/s^2})} = 36.2\,\mathrm{m}.$$

As this is greater than the 33.5-m height each car has to climb, both cars should be able to make it to the top of the hill.

6.129

If the total energy consumption in a day is E, then the metabolic rate is E/t, where $t = 1\,\mathrm{d} = 86\,400\,\mathrm{s}$. With $E = 10\,\mathrm{MJ} = 1.0 \times 10^7\,\mathrm{J}$, the rate is $E/t = 1.0 \times 10^7\,\mathrm{J}/86\,400\,\mathrm{s} = 1.2 \times 10^2\,\mathrm{W}$. According to the definition given in the problem statement, $\mathrm{BMR} = 90\,\mathrm{W}/1.5\,\mathrm{m^2} = 60\,\mathrm{W/m^2}$.

6.130

If the rate of oxygen consumption is N liters/s, then the rate at which energy is liberated by oxygen in the human body is $(N\,\text{liters/s})(2.0 \times 10^4\,\text{J/liter}) = 2.0N \times 10^4\,\mathrm{J/s}$. Equate this rate with the 77-W needed to obtain $2.0N \times 10^4\,\mathrm{J/s} = 77\,\mathrm{W} = 77\,\mathrm{J/s}$, or $N = 3.9 \times 10^{-3}$, meaning that the oxygen consumption rate is 3.9×10^{-3} liters/s.

6.131

From Problem (6.130) we know that the internal energy liberated by 1 liter of oxygen is $2.0 \times 10^4\,\mathrm{J}$. Since the person in question consumes oxygen at a rate of 0.40 liter/min, or $(0.40\,\text{liter/min})(1\,\text{min}/60\,\mathrm{s}) = 6.67 \times 10^{-3}$ liter/s, the rate of energy consumption for the person is $(6.67 \times 10^{-3}\,\text{liter/s})(2.0 \times 10^4\,\text{J/liter}) = 133\,\mathrm{W}$. Then with the definition of BMR found in Problem (6.129)

$$\mathrm{BMR} = \frac{\text{rate of energy consumption}}{\text{skin surface area}} = 133\,\mathrm{W}/1.8\,\mathrm{m} = 74\,\mathrm{W/m^2}.$$