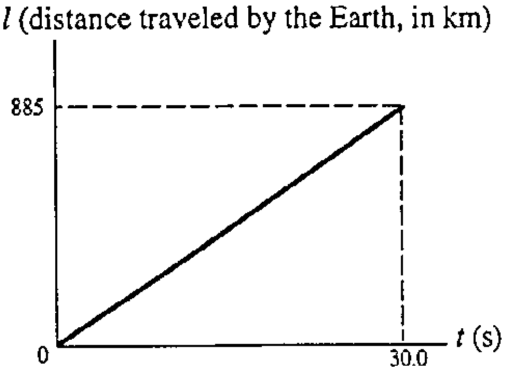
Solutions to Problems

2.1

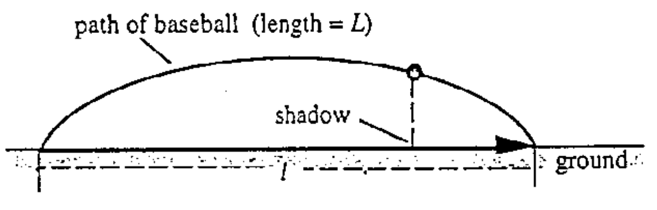
The average orbital speed of the Earth is given by Eq. (2.1):

$$v_{av} = \frac{l}{t} = \frac{885\,\text{km}}{30.0\,\text{s}} = 29.5\,\text{km/s}.$$

The distance vs time diagram for the orbital motion of the Earth is shown to the right, in which v_{av} is represented by the slope of the straight line in the plot.



2.2



According to Eq. (2.1), the average speed of the shadow (S) is given by

$$v_S = \frac{l}{t} = \frac{180\,\text{m}}{2.0\,\text{s}} = 90\,\text{m/s}.$$

The ball travels in an arc, whose length L is greater than l, the length of the shadow the arc projects onto the ground; hence the average speed of the ball, $v_B = L/t$, is greater than v_S. (In general, since the light rays from the Sun are essentially parallel, $l \le L$, where the equality is valid only if the path of the baseball is contained in a horizontal plane, which is certainly impossible in a free fall under the influence of gravity.)

2.11

(a) The length of each of the two segments of the trip is given by $l = (30\,\text{km})/2 = 15\,\text{km}$. Thus for the first segment

$$v_{av} = \frac{l}{t_1} = \frac{15\,\text{km}}{(15\,\text{min})(1.0\,\text{h}/60\,\text{min})} = 60\,\text{km/h},$$

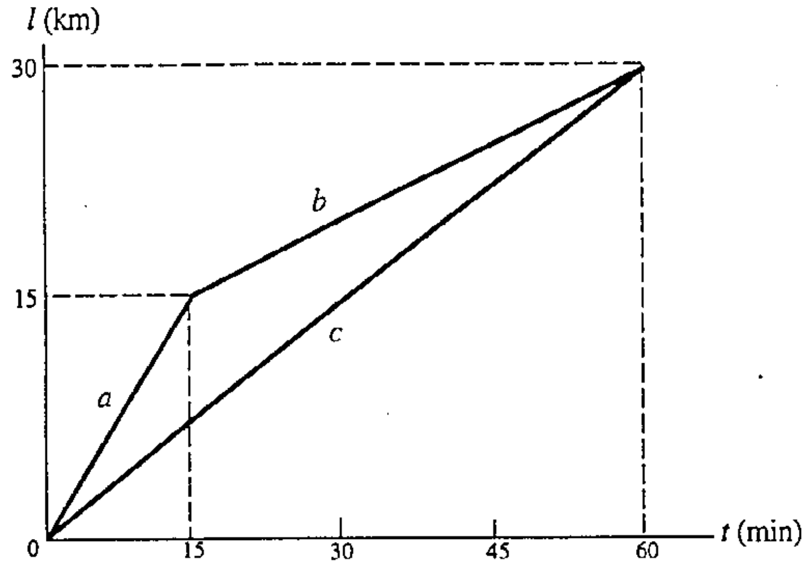
and for the second one

$$v_{av} = \frac{l}{t_2} = \frac{15\,\text{km}}{(45\,\text{min})(1.0\,\text{h}/60\,\text{min})} = 20\,\text{km/h}.$$

(b) For the whole trip the total distance covered is $l_{total} = 30\,\text{km}$, while the total time elapsed is $t = t_1 + t_2 = 15\,\text{min} + 45\,\text{min} = 60\,\text{min}$. Thus the average speed for the whole trip is

$$V_{av} = \frac{l_{total}}{t} = \frac{30\,\text{km}}{(60\,\text{min})(1.0\,\text{h}/60\,\text{min})} = 30\,\text{km/h}\,.$$

The distance vs time diagram is shown below. The average speeds for the first, second segment and the whole trip are represented by the slopes of lines a, b and c in the plot, respectively.



2.12

(a) First, convert the time-of-flight t to seconds: $t = 3\,\text{h}\;47\,\text{min}\;36\,\text{s} = (3\,\text{h})(3600\,\text{s/h}) + (47\,\text{min})(60\,\text{s/min}) + 36\,\text{s} = 10\,800\,\text{s} + 2820\,\text{s} + 36\,\text{s} = 13\,656\,\text{s}$. Thus from Eq. (2.1) the average speed of the plane is

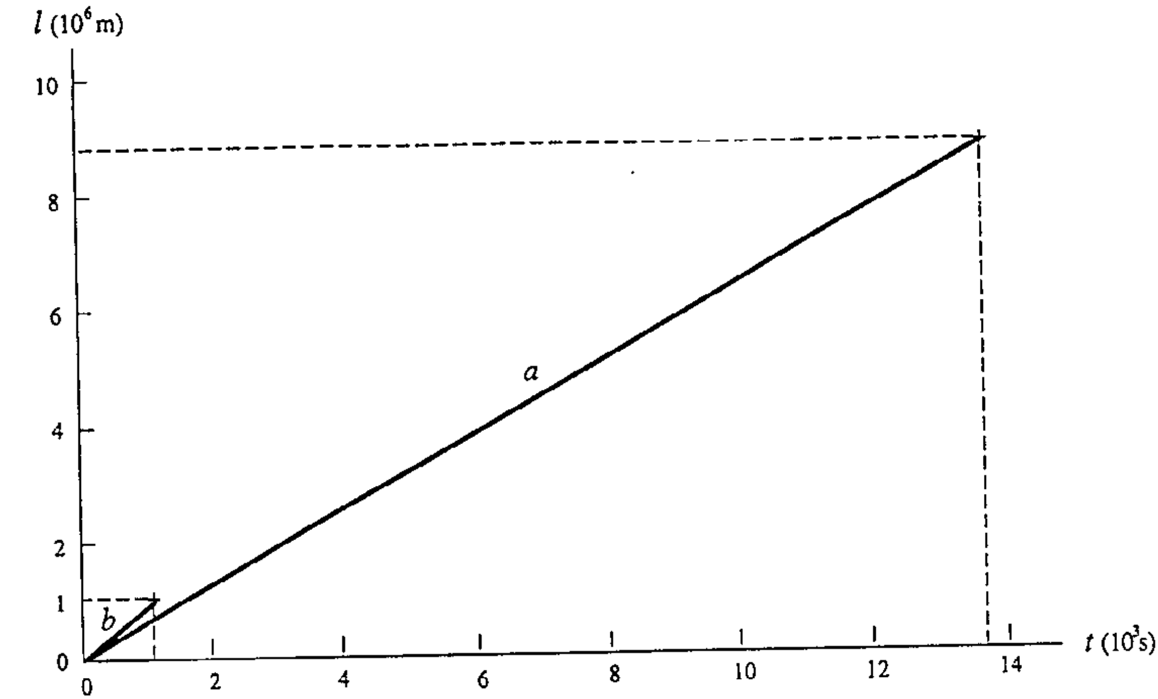
$$V_{av} = \frac{l}{t} = \frac{(8790\,\text{km})(1000\,\text{m/km})}{13\,656\,\text{s}} = 643.7\,\text{m/s}\,.$$

(b) Now $l = 1000\,\text{km}$ and $V_{av} = 935.1\,\text{m/s}$. Thus from Eq. (2.1)

$$t = \frac{l}{V_{av}} = \frac{(1000\,\text{km})(1000\,\text{m/km})}{935.1\,\text{m/s}} = 1.07 \times 10^3\,\text{s}\,.$$

This is $(1.07 \times 10^3\,\text{s})(1.000\,\text{min}/60.00\,\text{s}) = 17.8\,\text{min}$, or $(1.07 \times 10^3\,\text{s})(1.000\,\text{h}/3\,600\,\text{s}) = 0.297\,\text{h}$.

The distance vs time diagrams for parts (a) and (b) above are shown in the next page.

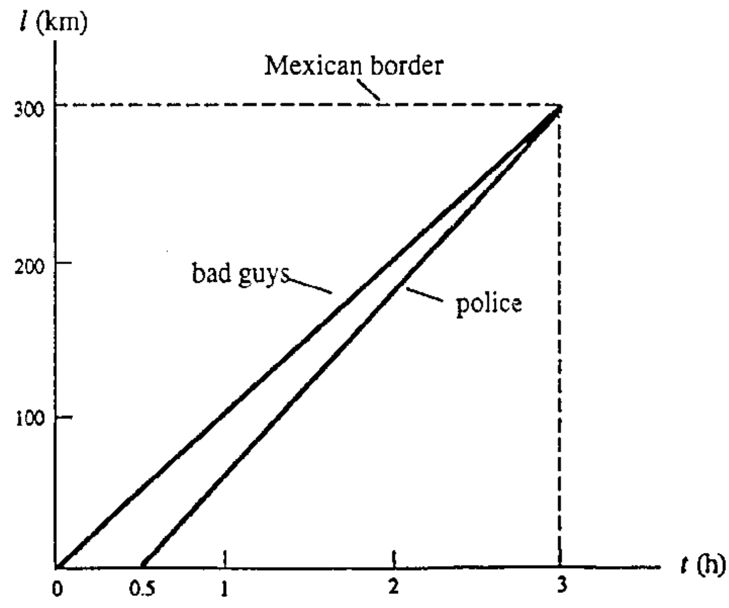


2.15

For the bad guys (B) we have $l_B = 300\,\text{km}$ and $v_B = 100\,\text{km/h}$. Thus the time it would take for the bad guys to reach the border is $t_B = l_B/v_B = 300\,\text{km}/(100\,\text{km/h}) = 3.00\,\text{h}$. Since they arrive one-half hour later, the cops (C) have no more than $t_C = 3.00\,\text{h} - 0.50\,\text{h} = 2.50\,\text{h}$ to make it to the border if they are to capture the crooks this side of the border. Thus the minimum speed the cops must have is

$$v_C = \frac{l_B}{t_C} = \frac{300\,\text{km}}{2.50\,\text{h}} = 120\,\text{km/h}\,.$$

The distance vs time diagrams for both the police and the bad guys are plotted below.



2.21

Use Eq. (2.1), $l = vt$.

(a) Change the unit of l from ft to m and solve for t from Eq. (2.1):

$$t = \frac{l}{v} = \frac{(1.0\,\text{ft})(0.3048\,\text{ft/m})}{2.998 \times 10^8\,\text{m/s}} = 1.0 \times 10^{-9}\,\text{s}.$$

(b) Now $l = 1000\,\text{m}$ so the light from something 1000 m away must have emitted a time

$$t = \frac{1000\,\text{m}}{2.998 \times 10^8\,\text{m/s}} = 3.336 \times 10^{-6}\,\text{s}$$

ago before it reaches your eyes.

2.23

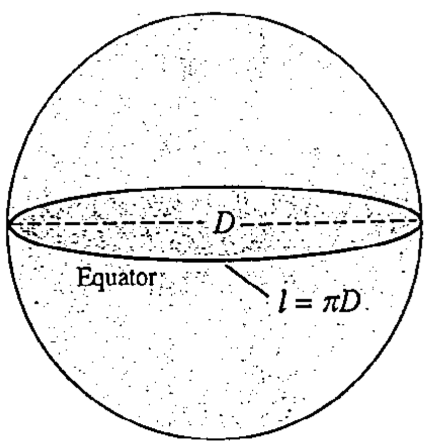
From the figure we see that the speed of the cat during the third second of its journey is $v = 2.0\,\text{m/s}$. Thus the distance it travels during the third second is $l = vt = (2.0\,\text{m/s})(1.0\,\text{s}) = 2.0\,\text{m}$. Further from the figure we find that the maximum speed occurs between $t = 4.0\,\text{s}$ and 5.0 s, and is given by $v_{max} = 4.0\,\text{m/s}$. The minimum speed is zero, which occurs at the beginning and the end of the journey ($t = 0.0\,\text{s}$ and 7.0 s). The speed is a constant ($= 2.0\,\text{m/s}$) between $t = 1.5\,\text{s}$ and 3.3 s, and it assumes another constant value ($= 4.0\,\text{m/s}$) between $t = 4.0\,\text{s}$ and 5.0 s.

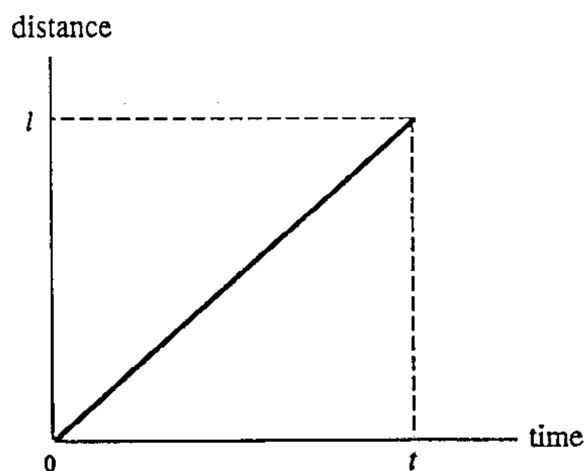
2.24

The distance l you travel in one day due to the rotation of the Earth is the circumference of the equatorial circle, which is given by $l = \pi D$, with D the diameter of the Earth. Note that $t = 1\,\text{d} = 23\,\text{h}\,56\,\text{min} = (23\,\text{h})(3600\,\text{s/min}) + (56\,\text{min})(60\,\text{s/min}) = 86\,160\,\text{s}$. Thus your speed is

$$v = \frac{\pi D}{t} = \frac{\pi(1.276 \times 10^7\,\text{m})}{86\,160\,\text{s}} = 465.3\,\text{m/s}.$$

The distance vs time diagram is shown in the next page.





2.31

The speed of the rocket is the time derivative of its height:

$$v(t) = \frac{dy}{dt} = \frac{d}{dt}[(4.8\,\mathrm{m/s})\,t] = 4.8\,\mathrm{m/s}\,.$$

At $t = 2.00\,\mathrm{s}$ its location is

$$y(t)\Big|_{t=2.00\,\mathrm{s}} = [(4.8\,\mathrm{m/s})\,t]\Big|_{t=2.00\,\mathrm{s}} = (4.8\,\mathrm{m/s})(2.00\,\mathrm{s}) = 9.6\,\mathrm{m}\,.$$

2.32

Take the derivative of $x(t)$ with respect to time t to obtain the speed v:

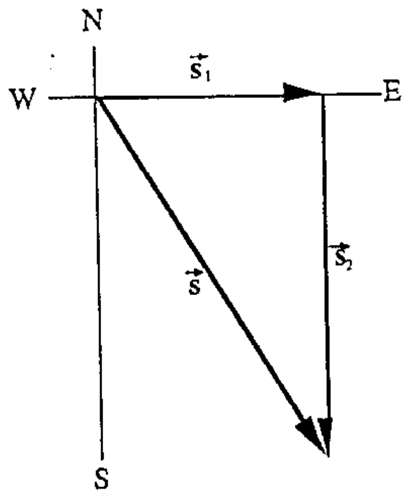
$$v(t) = \frac{dx}{dt} = \frac{d}{dt}[4.0\,\mathrm{m} + (8.2\,\mathrm{m/s})\,t] = 8.2\,\mathrm{m/s}\,,$$

which is a constant. Substitute $t = 0$ into $x(t)$ to obtain the location of the ball at $t = 0$:

$$x(t)\Big|_{t=0} = [4.0\,\mathrm{m} + (8.2\,\mathrm{m/s})\,t]\Big|_{t=0} = 4.0\,\mathrm{m}\,.$$

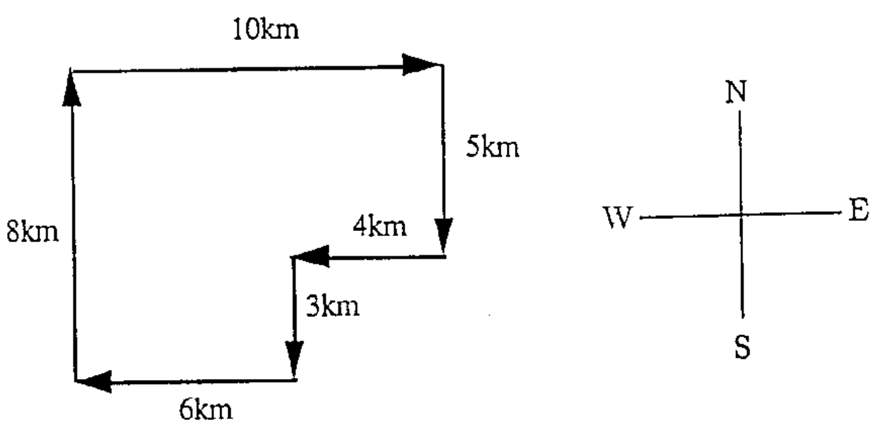
2.55

The displacement $\vec{s}$ of the robot consists of two segments, $\vec{s}_1$ (due east) and $\vec{s}_2$ (due south), as shown in the diagram to the right. Since $\vec{s}_1 \perp \vec{s}_2$,



$$\begin{aligned} s &= \sqrt{s_1^2 + s_2^2} \\ &= \sqrt{(9.0\,\mathrm{km})^2 + (12\,\mathrm{km})^2} \\ &= 15\,\mathrm{km}\,. \end{aligned}$$

2.61



From the displacement diagram shown above we find that the boy scout ends up right where they started, meaning that their net displacement is zero. The distance they marched is given by $l = 10\,\mathrm{km} + 5.0\,\mathrm{km} + 4.0\,\mathrm{km} + 3.0\,\mathrm{km} + 6.0\,\mathrm{km} + 8.0\,\mathrm{km} = 36\,\mathrm{km}$.

2.75

Use Eq. (2.1) to find the average speed and Eq. (2.7) for the average velocity. The average speed is

$$v_{av} = \frac{l}{t} = \frac{43\,\mathrm{m}}{10\,\mathrm{s}} = 4.3\,\mathrm{m/s}\,;$$

while the average velocity is

$$\vec{\mathbf{v}}_{av} = \frac{\vec{s}}{t} = \frac{(3.0\,\mathrm{m})\text{-south}}{10\,\mathrm{s}} = (0.30\,\mathrm{m/s})\text{-south}\,.$$

2.91

$$\vec{\mathbf{A}} + \vec{\mathbf{B}} = (4.0\hat{\imath} - 2.0\hat{\jmath}) + (-1.0\hat{\imath} - 2.0\hat{\jmath}) = (4.0 - 1.0)\hat{\imath} + (-2.0 - 2.0\hat{\jmath}) = 3.0\hat{\imath} - 4.0\hat{\jmath}\,.$$

2.93

In a displacement vs time diagram, the velocity is represented by the local slope of the curve. If a portion of the curve is a straight line with a constant slope, then the velocity is a constant for that portion of the motion. Thus the velocity of the toy train is a constant from 0 to 4.0 s, from 5.0 to 6.0 s, from 6.0 to 7.0 s, and from 7.0 to 8.0 s.

The slope at $t = 2.0\,\mathrm{s}$ is given by

$$\text{slope} = \frac{\text{rise}}{\text{run}} = \frac{4.0\,\mathrm{m} - 0.0\,\mathrm{m}}{4.0\,\mathrm{s} - 0.0\,\mathrm{s}} = 1.0\,\mathrm{m/s}\,,$$

so the speed at that time is 1.0 m/s. The slope at $t = 6.5\,\mathrm{s}$ is obviously zero, so $v = 0$ at $t = 6.5\,\mathrm{s}$.

When the slope reverses its sign, so does the velocity. Thus the velocity changes its direction at around $t = 4.5\,\mathrm{s}$.

2.120

Denote the ship, the lady bug, the person, and the Earth with subscripts S, L, P and E, respectively, and use Eq. (2.19).

(a) $\vec{\mathbf{v}}_{LS} = \vec{\mathbf{v}}_{LP} + \vec{\mathbf{v}}_{PS} = (0.01\,\mathrm{km/h})\text{-south} + (5.00\,\mathrm{km/h})\text{-south} = (5.01\,\mathrm{km/h})\text{-south}.$

(b) Since $\vec{\mathbf{v}}_{PS} = (5.00\,\mathrm{km/h})\text{-south} = (-5.00\,\mathrm{km/h})\text{-north}$,

$$\vec{\mathbf{v}}_{PE} = \vec{\mathbf{v}}_{PS} + \vec{\mathbf{v}}_{SE} = (-5.00\,\mathrm{km/h})\text{-north} + (15.0\,\mathrm{km/h})\text{-north} = (10.0\,\mathrm{km/h})\text{-north}\,.$$

(c) Since $\vec{\mathbf{v}}_{LS} = (5.01\,\mathrm{km/h})\text{-south} = (-5.01\,\mathrm{km/h})\text{-north}$ [see part (a) above],

$$\vec{\mathbf{v}}_{LE} = \vec{\mathbf{v}}_{LS} + \vec{\mathbf{v}}_{SE} = (-5.01\,\mathrm{km/h})\text{-north} + (15.0\,\mathrm{km/h})\text{-north} = (9.99\,\mathrm{km/h})\text{-north}\,;$$

2.131

From Fig. P131 we see that the author was moving in a circle of radius $R_\theta = R\cos\theta$ (as $\cos\theta = R_\theta/R$). The circumference of the circle is then

$$l = 2\pi R_\theta = 2\pi R\cos\theta = 2\pi(6400\,\text{km})(\cos 41^\circ) = 3.0\times10^4\,\text{km}.$$

Since he covers that much distance in $t = 24\,\text{h}$, the author's average speed is

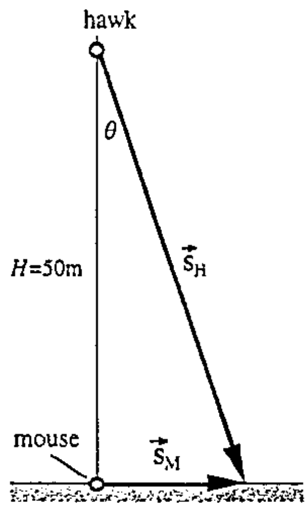
$$v_{av} = \frac{l}{t} = \frac{3.0\times10^4\,\text{km}}{24\,\text{h}} = 1.3\times10^3\,\text{km/h},$$

or $(1.26\times10^3\,\text{km/h})(1.0\,\text{mi}/1.609\,\text{km}) = 7.9\times10^2\,\text{mi/h}$. If you know your local latitude angle θ, you can use $l = 2\pi R\cos\theta$ and $v_{av} = 2\pi R\cos\theta/t$ to find the corresponding value of v_{av} where you are.

2.133

In the diagram shown to the right $\vec{s}_H = \vec{v}_H t$ is the displacement of the hawk (H), and $\vec{s}_M = \vec{v}_M t$ is that of the mouse (M). Here $|\vec{v}_H|$ is the desired speed of the hawk, $|\vec{v}_M| = 2.0\,\text{m/s}$, and $t = 5.0\,\text{s}$. Use the Pythagorean Theorem to obtain $H^2 + s_M^2 = s_H^2$, or $H^2 + (|\vec{v}_M|t)^2 = (|\vec{v}_H|t)^2$, from which we solve for $|\vec{v}_H|$:

$$|\vec{v}_H| = \frac{\sqrt{H^2 + |\vec{v}_M|^2 t^2}}{t} = \frac{\sqrt{(50\,\text{m})^2 + [(2.0\,\text{m/s})(5.0\,\text{s})]^2}}{5.0\,\text{s}} = 10\,\text{m/s}.$$



$\vec{v}_H$ should make an angle θ with respect to the vertical direction, where

$$\tan\theta = \frac{s_M}{H} = \frac{|\vec{v}_M|t}{H} = \frac{(2.0\,\text{m/s})(5.0\,\text{s})}{50\,\text{m}} = 0.20.$$

The angle is $\theta = \tan^{-1}(0.20) = 11^\circ$.