$\boxed{\textbf{E8-1}}$ An n-dimensional object can be oriented by stating the position of n different *carefully chosen* points P_i inside the body. Since each point has n coordinates, one might think there are n^2 coordinates required to completely specify the position of the body. But if the body is rigid then the distances between the points are fixed. There is a distance d_{ij} for every pair of points P_i and P_j. For each distance d_{ij} we need one fewer coordinate to specify the position of the body. There are $n(n-1)/2$ ways to connect n objects in pairs, so $n^2 - n(n-1)/2 = n(n+1)/2$ is the number of coordinates required.

E8-2 (1 rev/min)(2π rad/rev)/(60 s/min) = 0.105 rad/s.

E8-3 (a) $\omega = a + 3bt^2 - 4ct^3$.
(b) $\alpha = 6bt - 12t^2$.

E8-4 (a) The radius is $r = (2.3\times10^4\text{ly})(3.0\times10^8\text{m/s}) = 6.9\times10^{12}\text{m}\cdot\text{y/s}$. The time to make one revolution is $t = (2\pi 6.9\times10^{12}\text{m}\cdot\text{y/s})/(250\times10^3\text{m/s}) = 1.7\times10^8\text{y}$.
(b) The Sun has made $4.5\times10^9\text{y}/1.7\times10^8\text{y} = 26$ revolutions.

$\boxed{\textbf{E8-5}}$ (a) Integrate.

$$\omega_z = \omega_0 + \int_0^t \left(4at^3 - 3bt^2\right) dt = \omega_0 + at^4 - bt^3$$

(b) Integrate, again.

$$\Delta\theta = \int_0^t \omega_z dt = \int_0^t \left(\omega_0 + at^4 - bt^3\right) dt = \omega_0 t + \frac{1}{5}at^5 - \frac{1}{4}bt^4$$

E8-6 (a) (1 rev/min)(2π rad/rev)/(60 s/min) = 0.105 rad/s.
(b) (1 rev/h)(2π rad/rev)/(3600 s/h) = 1.75×10^{-3} rad/s.
(c) (1/12 rev/h)(2π rad/rev)/(3600 s/h) = 1.45×10^{-3} rad/s.

E8-7 85 mi/h = 125 ft/s. The ball takes t = (60 ft)/(125 ft/s) = 0.48 s to reach the plate. It makes (30 rev/s)(0.48 s) = 14 revolutions in that time.

E8-8 It takes $t = \sqrt{2(10\,\text{m})/(9.81\,\text{m/s}^2)} = 1.43\,\text{s}$ to fall 10 m. The average angular velocity is then $\omega = (2.5)(2\pi\text{ rad})/(1.43\,\text{s}) = 11$ rad/s.

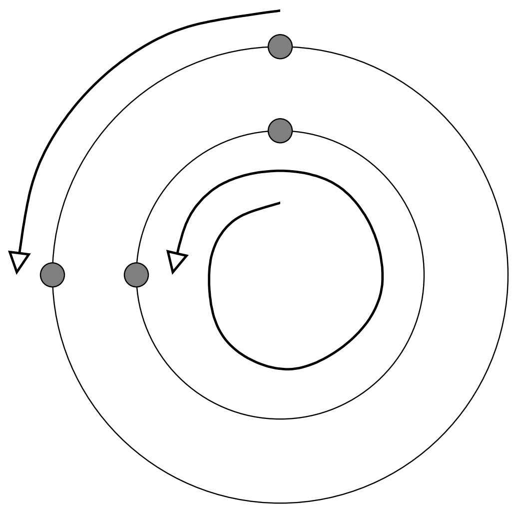
$\boxed{\textbf{E8-9}}$ (a) Since there are eight spokes, this means the wheel can make no more than 1/8 of a revolution while the arrow traverses the plane of the wheel. The wheel rotates at 2.5 rev/s; it makes one revolution every 1/2.5 = 0.4 s; so the arrow must pass through the wheel in less than 0.4/8 = 0.05 s.

The arrow is 0.24 m long, and it must move at least one arrow length in 0.05 s. The corresponding minimum speed is (0.24 m)/(0.05 s) = 4.8 m/s.

(b) It does not matter where you aim, because the wheel is rigid. It is the angle through which the spokes have turned, not the distance, which matters here.

E8-10 We look for the times when the Sun, the Earth, and the other planet are collinear in some specified order.

Since the outer planets revolve around the Sun more slowly than Earth, after one year the Earth has returned to the original position, but the outer planet has completed *less* than one revolution. The Earth will then "catch up" with the outer planet *before* the planet has completed a revolution. If θ_E is the angle through which Earth moved and θ_P is the angle through which the planet moved, then $\theta_E = \theta_P + 2\pi$, since the Earth completed one more revolution than the planet.



If ω_P is the angular velocity of the planet, then the angle through which it moves during the time T_S (the time for the planet to line up with the Earth). Then

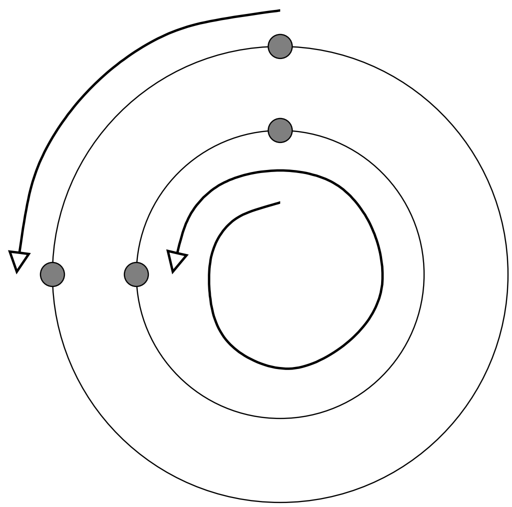
$$\begin{aligned}\theta_E &= \theta_P + 2\pi,\\ \omega_E T_S &= \omega_P T_S + 2\pi,\\ \omega_E &= \omega_P + 2\pi/T_S\end{aligned}$$

The angular velocity of a planet is $\omega = 2\pi/T$, where T is the period of revolution. Substituting this into the last equation above yields

$$1/T_E = 1/T_P + 1/T_S.$$

$\boxed{\textbf{E8-11}}$ We look for the times when the Sun, the Earth, and the other planet are collinear in some specified order.

Since the inner planets revolve around the Sun more quickly than Earth, after one year the Earth has returned to the original position, but the inner planet has completed *more* than one revolution. The inner planet must then have "caught-up" with the Earth *before* the Earth has completed a revolution. If θ_E is the angle through which Earth moved and θ_P is the angle through which the planet moved, then $\theta_P = \theta_E + 2\pi$, since the inner planet completed one more revolution than the Earth.



If ω_P is the angular velocity of the planet, then the angle through which it moves during the time T_S (the time for the planet to line up with the Earth). Then

$$\begin{aligned}\theta_P &= \theta_E + 2\pi,\\ \omega_P T_S &= \omega_E T_S + 2\pi,\\ \omega_P &= \omega_E + 2\pi/T_S\end{aligned}$$

The angular velocity of a planet is $\omega = 2\pi/T$, where T is the period of revolution. Substituting this into the last equation above yields

$$1/T_P = 1/T_E + 1/T_S.$$

E8-12 (a) $\alpha = (-78 \text{ rev/min})/(0.533 \text{ min}) = -150 \text{ rev/min}^2$.

(b) Average angular speed while slowing down is 39 rev/min, so (39 rev/min)(0.533 min) = 21 rev.

E8-13 (a) $\alpha = (2880 \text{ rev/min} - 1170 \text{ rev/min})/(0.210 \text{ min}) = 8140 \text{ rev/min}^2$.

(b) Average angular speed while accelerating is 2030 rev/min, so (2030 rev/min)(0.210 min) = 425 rev.

E8-14 Find area under curve.

$$\frac{1}{2}(5 \text{ min} + 2.5 \text{ min})(3000 \text{ rev/min}) = 1.13\times 10^4 \text{ rev}.$$

$\boxed{\textbf{E8-15}}$ (a) $\omega_{0z} = 25.2$ rad/s; $\omega_z = 0$; $t = 19.7$ s; and α_z and ϕ are unknown. From Eq. 8-6,

$$\begin{aligned}\omega_z &= \omega_{0z} + \alpha_z t,\\ (0) &= (25.2 \text{ rad/s}) + \alpha_z(19.7 \text{ s}),\\ \alpha_z &= -1.28 \text{ rad/s}^2\end{aligned}$$

(b) We use Eq. 8-7 to find the angle through which the wheel rotates.

$$\phi = \phi_0 + \omega_{0z}t + \frac{1}{2}\alpha_z t^2 = (0) + (25.2 \text{ rad/s})(19.7 \text{ s}) + \frac{1}{2}(-1.28 \text{ rad/s}^2)(19.7 \text{ s})^2 = 248 \text{ rad}.$$

(c) $\phi = 248 \text{ rad}\frac{1 \text{ rev}}{2\pi \text{ rad}} = 39.5$ rev.

E8-16 (a) $\alpha = (225 \text{ rev/min} - 315 \text{ rev/min})/(1.00 \text{ min}) = -90.0 \text{ rev/min}^2$.
(b) $t = (0 - 225 \text{ rev/min})/(-90.0 \text{ rev/min}^2) = 2.50$ min.
(c) $(-90.0 \text{ rev/min}^2)(2.50 \text{ min})^2/2 + (225 \text{ rev/min})(2.50 \text{ min}) = 281$ rev.

E8-17 (a) The average angular speed was $(90 \text{ rev})/(15\,\text{s}) = 6.0$ rev/s. The angular speed at the beginning of the interval was then $2(6.0 \text{ rev/s}) - (10 \text{ rev/s}) = 2.0$ rev/s.

(b) The angular acceleration was $(10 \text{ rev/s} - 2.0 \text{ rev/s})/(15\,\text{s}) = 0.533 \text{ rev/s}^2$. The time required to get the wheel to 2.0 rev/s was $t = (2.0 \text{ rev/s})/(0.533 \text{ rev/s}^2) = 3.8\,\text{s}$.

E8-18 (a) The wheel will rotate through an angle ϕ where

$$\phi = (563 \text{ cm})/(8.14 \text{ cm}/2) = 138 \text{ rad}.$$

(b) $t = \sqrt{2(138 \text{ rad})/(1.47 \text{ rad/s}^2)} = 13.7\,\text{s}$.

$\boxed{\textbf{E8-19}}$ (a) We are given $\phi = 42.3$ rev$= 266$ rad, $\omega_{0z} = 1.44$ rad/s, and $\omega_z = 0$. Assuming a uniform deceleration, the average angular velocity during the interval is

$$\omega_{\text{av},z} = \frac{1}{2}(\omega_{0z} + \omega_z) = 0.72 \text{ rad/s}.$$

Then the time taken for deceleration is given by $\phi = \omega_{\text{av},z}t$, so $t = 369$ s.

(b) The angular acceleration can be found from Eq. 8-6,

$$\begin{aligned} \omega_z &= \omega_{0z} + \alpha_z t, \\ (0) &= (1.44 \text{ rad/s}) + \alpha_z(369 \text{ s}), \\ \alpha_z &= -3.9 \times 10^{-3} \text{ rad/s}^2. \end{aligned}$$

(c) We'll solve Eq. 8-7 for t,

$$\begin{aligned} \phi &= \phi_0 + \omega_{0z}t + \frac{1}{2}\alpha_z t^2, \\ (133 \text{ rad}) &= (0) + (1.44 \text{ rad/s})t + \frac{1}{2}(-3.9 \times 10^{-3} \text{ rad/s}^2)t^2, \\ 0 &= -133 + (1.44\,\text{s}^{-1})t - (-1.95 \times 10^{-3}\text{s}^{-2})t^2. \end{aligned}$$

Solving this quadratic expression yields two answers: $t = 108$ s and $t = 630$ s.

E8-20 The angular acceleration is $\alpha = (4.96 \text{ rad/s})/(2.33\,\text{s}) = 2.13 \text{ rad/s}^2$. The angle through which the wheel turned while accelerating is $\phi = (2.13 \text{ rad/s}^2)(23.0\,\text{s})^2/2 = 563$ rad. The angular speed at this time is $\omega = (2.13 \text{ rad/s}^2)(23.0\,\text{s}) = 49.0$ rad/s. The wheel spins through an additional angle of $(49.0 \text{ rad/s})(46\,\text{s} - 23\,\text{s}) = 1130$ rad, for a total angle of 1690 rad.

E8-21 $\omega = (14.6\,\text{m/s})/(110\,\text{m}) = 0.133$ rad/s.

E8-22 The linear acceleration is $(25\,\text{m/s} - 12\,\text{m/s})/(6.2\,\text{s}) = 2.1\,\text{m/s}^2$. The angular acceleration is $\alpha = (2.1\,\text{m/s}^2)/(0.75\,\text{m}/2) = 5.6$ rad/s.

$\boxed{\textbf{E8-23}}$ (a) The angular speed is given by $v_T = \omega r$. So $\omega = v_T/r = (28,700$ km/hr$)/(3220$ km$) = 8.91$ rad/hr. That's the same thing as 2.48×10^{-3} rad/s.

(b) $a_R = \omega^2 r = (8.91 \text{ rad/h})^2(3220 \text{ km}) = 256000 \text{ km/h}^2$, or

$$a_R = 256000 \text{ km/h}^2(1/3600 \text{ h/s})^2(1000 \text{ m/km}) = 19.8\,\text{m/s}^2.$$

(c) If the speed is constant then the tangential acceleration is zero, regardless of the shape of the trajectory!

E8-24 The bar needs to make

$$(1.50 \text{ cm})(12.0 \text{ turns/cm}) = 18 \text{ turns}.$$

This will happen is $(18 \text{ rev})/(237 \text{ rev/min}) = 4.56\,\text{s}$.

E8-25 (a) The angular speed is $\omega = (2\pi \text{ rad})/(86400\,\text{s}) = 7.27\times10^{-5}$ rad/s.

(b) The distance from the polar axis is $r = (6.37\times10^6\text{m})\cos(40^\circ) = 4.88\times10^6\text{m}$. The linear speed is then $v = (7.27\times10^{-5} \text{ rad/s})(4.88\times10^6\text{m}) = 355\,\text{m/s}$.

(c) The angular speed is the same as part (a). The distance from the polar axis is $r = (6.37\times 10^6\text{m})\cos(0^\circ) = 6.37\times10^6\text{m}$. The linear speed is then $v = (7.27\times10^{-5} \text{ rad/s})(6.37\times10^6\text{m}) = 463\,\text{m/s}$.

E8-26 (a) $a_\text{T} = (14.2 \text{ rad/s}^2)(0.0283\,\text{m}) = 0.402\,\text{m/s}^2$.

(b) Full speed is $\omega = 289$ rad/s. $a_\text{R} = (289 \text{ rad/s})^2(0.0283\,\text{m}) = 2360\,\text{m/s}^2$.

(c) It takes

$$t = (289 \text{ rad/s})/(14.2 \text{ rad/s}^2) = 20.4\,\text{s}$$

to get up to full speed. Then $x = (0.402\,\text{m/s}^2)(20.4\,\text{s})^2/2 = 83.6\,\text{m}$ is the distance through which a point on the rim moves.

$\boxed{\textbf{E8-27}}$ (a) The pilot sees the propeller rotate, no more. So the tip of the propeller is moving with a tangential velocity of $v_T = \omega r = (2000 \text{ rev/min})(2\pi \text{ rad/rev})(1.5 \text{ m}) = 18900$ m/min. This is the same thing as 315 m/s.

(b) The observer on the ground sees this tangential motion and sees the forward motion of the plane. These two velocity components are perpendicular, so the magnitude of the sum is $\sqrt{(315\,\text{m/s})^2 + (133\,\text{m/s})^2} = 342\,\text{m/s}$.

E8-28 $a_\text{T} = a_\text{R}$ when $r\alpha = r\omega^2 = r(\alpha t)^2$, or $t = \sqrt{1/(0.236 \text{ rad/s}^2)} = 2.06\,\text{s}$.

E8-29 (a) $a_\text{R} = r\omega^2 = r\alpha^2 t^2$.

(b) $a_\text{T} = r\alpha$.

(c) Since $a_\text{R} = a_\text{T}\tan(57.0^\circ)$, $t = \sqrt{\tan(57.0^\circ)/\alpha}$. Then

$$\phi = \frac{1}{2}\alpha t^2 = \frac{1}{2}\tan(57.0^\circ) = 0.77 \text{ rad} = 44.1^\circ.$$

E8-30 (a) The tangential speed of the edge of the wheel relative axle is $v = 27\,\text{m/s}$. $\omega = (27\,\text{m/s})/(0.38\,\text{m}) = 71$ rad/s.

(b) The average angular speed while slowing is 71 rad/s/2, the time required to stop is then $t = (30 \times 2\pi \text{ rad})/(71 \text{ rad/s}/2) = 5.3\,\text{s}$. The angular acceleration is then $\alpha = (-71 \text{ rad/s})/(5.3\,\text{s}) = -13$ rad/s.

(c) The car moves forward $(27\,\text{m/s}/2)(5.3\,\text{s}) = 72\,\text{m}$.

E8-31 Yes, the speed would be wrong. The angular velocity of the small wheel would be $\omega = v_\mathrm{t}/r_\mathrm{s}$, but the reported velocity would be $v = \omega r_\mathrm{l} = v_\mathrm{t} r_\mathrm{l}/r_\mathrm{s}$. This would be in error by a fraction

$$\frac{\Delta v}{v_\mathrm{t}} = \frac{(72\ \mathrm{cm})}{(62\ \mathrm{cm})} - 1 = 0.16.$$

E8-32 (a) Square both equations and then add them:

$$x^2 + y^2 = (R\cos\omega t)^2 + (R\sin\omega t)^2 = R^2,$$

which is the equation for a circle of radius R.

(b) $v_x = -R\omega\sin\omega t = -\omega y$; $v_y = R\omega\cos\omega t = \omega x$. Square and add, $v = \omega R$. The direction is tangent to the circle.

(b) $a_x = -R\omega^2\cos\omega t = -\omega^2 x$; $a_y = -R\omega^2\sin\omega t = -\omega^2 y$. Square and add, $a = \omega^2 R$. The direction is toward the center.

$\boxed{\textbf{E8-33}}$ (a) The object is "slowing down", so $\vec{\alpha} = (-2.66\ \mathrm{rad/s^2})\hat{\mathbf{k}}$. We know the direction because it is rotating about the z axis and we are given the direction of $\vec{\omega}$. Then from Eq. 8-19, $\vec{\mathbf{v}} = \vec{\omega}\times\vec{\mathbf{R}} = (14.3\ \mathrm{rad/s})\hat{\mathbf{k}}\times[(1.83\ \mathrm{m})\hat{\mathbf{j}} + (1.26\ \mathrm{m})\hat{\mathbf{k}}]$. But only the cross term $\hat{\mathbf{k}}\times\hat{\mathbf{j}}$ survives, so $\vec{\mathbf{v}} = (-26.2\,\mathrm{m/s})\hat{\mathbf{i}}$.

(b) We find the acceleration from Eq. 8-21,

$$\begin{aligned}
\vec{\mathbf{a}} &= \vec{\alpha}\times\vec{\mathbf{R}} + \vec{\omega}\times\vec{\mathbf{v}},\\
&= (-2.66\ \mathrm{rad/s^2})\hat{\mathbf{k}}\times[(1.83\,\mathrm{m})\hat{\mathbf{j}} + (1.26\,\mathrm{m})\hat{\mathbf{k}}] + (14.3\ \mathrm{rad/s})\hat{\mathbf{k}}\times(-26.2\,\mathrm{m/s})\hat{\mathbf{i}},\\
&= (4.87\,\mathrm{m/s^2})\hat{\mathbf{i}} + (-375\,\mathrm{m/s^2})\hat{\mathbf{j}}.
\end{aligned}$$

E8-34 (a) $\vec{\mathbf{F}} = -2m\vec{\omega}\times\vec{\mathbf{v}} = -2m\omega v\cos\theta$, where θ is the latitude. Then

$$F = 2(12\,\mathrm{kg})(2\pi\ \mathrm{rad}/86400\,\mathrm{s})(35\,\mathrm{m/s})\cos(45^\circ) = 0.043\,\mathrm{N},$$

and is directed *west*.

(b) Reversing the velocity will reverse the direction, so *east*.

(c) No. The Coriolis force pushes it to the west on the way up and gives it a westerly velocity; on the way down the Coriolis force slows down the westerly motion, but does not push it back east. The object lands to the west of the starting point.

P8-1 (a) $\omega = (4.0\ \mathrm{rad/s}) - (6.0\ \mathrm{rad/s^2})t + (3.0\ \mathrm{rad/s})t^2$. Then $\omega(2.0\,\mathrm{s}) = 4.0\ \mathrm{rad/s}$ and $\omega(4.0\,\mathrm{s}) = 28.0\ \mathrm{rad/s}$.

(b) $\alpha_\mathrm{av} = (28.0\ \mathrm{rad/s} - 4.0\ \mathrm{rad/s})/(4.0\,\mathrm{s} - 2.0\,\mathrm{s}) = 12\ \mathrm{rad/s^2}$.

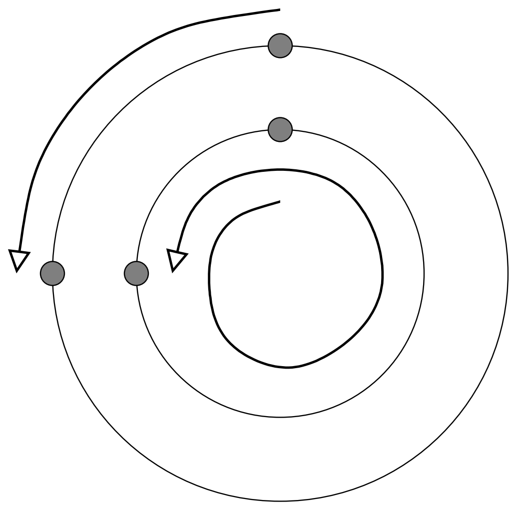
(c) $\alpha = -(6.0\ \mathrm{rad/s^2}) + (6.0\ \mathrm{rad/s})t$. Then $\alpha(2.0\,\mathrm{s}) = 6.0\ \mathrm{rad/s^2}$ and $\alpha(4.0\,\mathrm{s}) = 18.0\ \mathrm{rad/s^2}$.

P8-2 If the wheel really does move counterclockwise at 4.0 rev/min, then it turns through

$$(4.0\ \mathrm{rev/min})/[(60\ \mathrm{s/min})(24\ \mathrm{frames/s})] = 2.78\times10^{-3}\ \mathrm{rev/frame}.$$

This means that a spoke has moved 2.78×10^{-3} rev. There are 16 spokes each located 1/16 of a revolution around the wheel. If instead of moving counterclockwise the wheel was instead moving clockwise so that a different spoke had moved $1/16\ \mathrm{rev} - 2.78\times10^{-3}\ \mathrm{rev} = 0.0597\ \mathrm{rev}$, then the same effect would be present. The wheel then would be turning clockwise with a speed of $\omega = (0.0597\ \mathrm{rev})(60\ \mathrm{s/min})(24\ \mathrm{frames/s}) = 86\ \mathrm{rev/min}$.

P8-3 (a) In the diagram below the Earth is shown at two locations a day apart. The Earth rotates clockwise in this figure.



Note that the Earth rotates through 2π rad in order to be correctly oriented for a complete sidereal day, but because the Earth has moved in the orbit it needs to go farther through an angle θ in order to complete a solar day. By the time the Earth has gone all of the way around the sun the total angle θ will be 2π rad, which means that there was one more sidereal day than solar day.

(b) There are (365.25 d)(24.000 h/d) $= 8.7660\times 10^3$ hours in a year with 265.25 solar days. But there are 366.25 sidereal days, so each one has a length of $8.7660\times 10^3/366.25 = 23.934$ hours, or 23 hours and 56 minutes and 4 seconds.

P8-4 (a) The period is time per complete rotation, so $\omega = 2\pi/T$.

(b) $\alpha = \Delta\omega/\Delta t$, so

$$\begin{aligned}
\alpha &= \left(\frac{2\pi}{T_0 + \Delta T} - \frac{2\pi}{T_0}\right)/(\Delta t),\\
&= \frac{2\pi}{\Delta t}\left(\frac{-\Delta T}{T_0(T_0 + \Delta T)}\right),\\
&\approx \frac{2\pi}{\Delta t}\frac{-\Delta T}{T_0^2},\\
&= \frac{2\pi}{(3.16\times 10^7\mathrm{s})}\frac{-(1.26\times 10^{-5}\mathrm{s})}{(0.033\,\mathrm{s})^2} = -2.30\times 10^{-9}\mathrm{rad/s}^2.
\end{aligned}$$

(c) $t = (2\pi/0.033\,\mathrm{s})/(2.30\times 10^{-9}\mathrm{rad/s}^2) = 8.28\times 10^{10}\mathrm{s}$, or 2600 years.

(d) $2\pi/T_0 = 2\pi/T - \alpha t$, or

$$T_0 = \Big(1/(0.033\,\mathrm{s}) - (-2.3\times 10^{-9}\mathrm{rad/s}^2)(3.0\times 10^{10}\,\mathrm{s})/(2\pi)\Big)^{-1} = 0.024\,\mathrm{s}.$$

$\boxed{\textbf{P8-5}}$ The final angular velocity during the acceleration phase is $\omega_z = \alpha_z t$ = (3.0 rad/s)(4.0 s) = 12.0 rad/s. Since both the acceleration and deceleration phases are uniform with endpoints $\omega_z = 0$, the average angular velocity for both phases is the same, and given by half of the maximum: $\omega_{\mathrm{av},z} = 6.0$ rad/s.

The angle through which the wheel turns is then

$$\phi = \omega_{\mathrm{av},z} t = (6.0 \text{ rad/s})(4.1\,\mathrm{s}) = 24.6 \text{ rad}.$$

The time is the total for *both* phases.

(a) The first student sees the wheel rotate through the smallest angle less than one revolution; this student would have no idea that the disk had rotated more than once. Since the disk moved through 3.92 revolutions, the first student will either assume the disk moved forward through 0.92 revolutions or backward through 0.08 revolutions.

(b) According to whom? We've already answered from the perspective of the second student.

P8-6 $\omega = (0.652 \text{ rad/s}^2)t$ and $\alpha = (0.652 \text{ rad/s}^2)$.

(a) $\omega = (0.652 \text{ rad/s}^2)(5.60\,\mathrm{s}) = 3.65 \text{ rad/s}$

(b) $v_{\mathrm{T}} = \omega r = (3.65 \text{ rad/s})(10.4\,\mathrm{m}) = 38\,\mathrm{m/s}$.

(c) $a_{\mathrm{T}} = \alpha r = (0.652 \text{ rad/s}^2)(10.4\,\mathrm{m}) = 6.78\,\mathrm{m/s}^2$.

(d) $a_{\mathrm{R}} = \omega^2 r = (3.65 \text{ rad/s})^2(10.4\,\mathrm{m}) = 139\,\mathrm{m/s}^2$.

P8-7 (a) $\omega = (2\pi \text{ rad})/(3.16\times10^7\,\mathrm{s}) = 1.99\times10^{-7} \text{ rad/s}$.

(b) $v_{\mathrm{T}} = \omega R = (1.99\times10^{-7} \text{ rad/s})(1.50\times10^{11}\mathrm{m}) = 2.99\times10^4\mathrm{m/s}$.

(c) $a_{\mathrm{R}} = \omega^2 R = (1.99\times10^{-7} \text{ rad/s})^2(1.50\times10^{11}\mathrm{m}) = 5.94\times10^{-3}\mathrm{m/s}^2$.

P8-8 (a) $\alpha = (-156 \text{ rev/min})/(2.2 \times 60 \text{ min}) = -1.18 \text{ rev/min}^2$.

(b) The average angular speed while slowing down is 78 rev/min, so the wheel turns through (78 rev/min)(2.2 × 60 min) = 10300 revolutions.

(c) $a_{\mathrm{T}} = (2\pi \text{ rad/rev})(-1.18 \text{ rev/min}^2)(0.524\,\mathrm{m}) = -3.89 \text{ m/min}^2$. That's the same as $-1.08\times 10^{-3}\mathrm{m/s}^2$.

(d) $a_{\mathrm{R}} = (2\pi \text{ rad/rev})(72.5 \text{ rev/min})^2(0.524\,\mathrm{m}) = 1.73 \times 10^4 \text{ m/min}^2$. That's the same as $4.81\mathrm{m/s}^2$. This is so much larger than the a_{T} term that the magnitude of the total linear acceleration is simply $4.81\mathrm{m/s}^2$.

$\boxed{\textbf{P8-9}}$ (a) There are 500 teeth (and 500 spaces between these teeth); so disk rotates $2\pi/500$ rad between the outgoing light pulse and the incoming light pulse. The light traveled 1000 m, so the elapsed time is $t = (1000\,\mathrm{m})/(3\times10^8 \text{ m/s}) = 3.33\times10^{-6}\mathrm{s}$.

Then the angular speed of the disk is $\omega_z = \phi/t = 1.26\times10^{-2} \text{ rad})/(3.33\times10^{-6}\mathrm{s}) = 3800 \text{ rad/s}$.

(b) The linear speed of a point on the edge of the would be

$$v_T = \omega R = (3800 \text{ rad/s})(0.05\,\mathrm{m}) = 190\,\mathrm{m/s}.$$

P8-10 The linear acceleration of the belt is $a = \alpha_A r_A$. The angular acceleration of C is $\alpha_C = a/r_C = \alpha_A(r_A/r_C)$. The time required for C to get up to speed is

$$t = \frac{(2\pi \text{ rad/rev})(100 \text{ rev/min})(1/60 \text{ min/s})}{(1.60 \text{ rad/s}^2)(10.0/25.0)} = 16.4\,\mathrm{s}.$$

P8-11 (a) The final angular speed is $\omega_{\mathrm{o}} = (130 \text{ cm/s})/(5.80 \text{ cm}) = 22.4 \text{ rad/s}$.

(b) The recording area is $\pi({R_{\mathrm{o}}}^2 - {R_{\mathrm{i}}}^2)$, the recorded track has a length l and width w, so

$$l = \frac{\pi[(5.80 \text{ cm})^2 - (2.50 \text{ cm}^2)]}{(1.60\times10^{-4} \text{ cm})} = 5.38\times10^5 \text{ cm}.$$

(c) Playing time is $t = (5.38\times10^5 \text{ cm})/(130 \text{ cm/s}) = 4140\,\mathrm{s}$, or 69 minutes.

P8-12 The angular position is given by $\phi = \arctan(vt/b)$. The derivative (Maple!) is

$$\omega = \frac{vb}{b^2 + v^2t^2},$$

and is directed *up*. Take the derivative again,

$$\alpha = \frac{2bv^3t}{(b^2 + v^2t^2)^2},$$

but is directed down.

$\boxed{\textbf{P8-13}}$ (a) Let the rocket sled move along the line $x = b$. The observer is at the origin and sees the rocket move with a constant angular speed, so the angle made with the x axis increases according to $\theta = \omega t$. The observer, rocket, and starting point form a right triangle; the position y of the rocket is the opposite side of this triangle, so

$$\tan\theta = y/b \text{ implies } y = b/\tan\omega t.$$

We want to take the derivative of this with respect to time and get

$$v(t) = \omega b/\cos^2(\omega t).$$

(b) The speed becomes infinite (which is clearly unphysical) when $t = \pi/2\omega$.