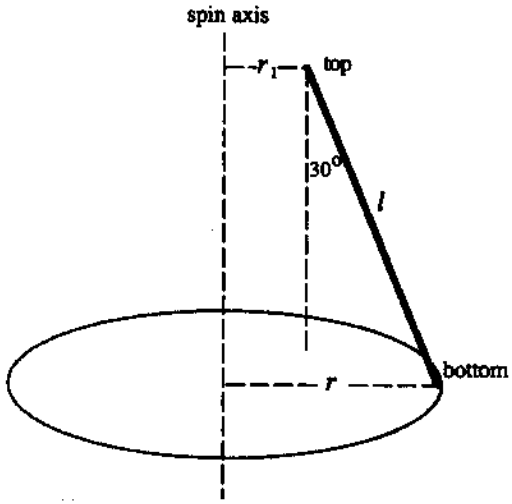
**5.3**

Just before the pebble (of mass $m = 25\,\text{g} = 0.025\,\text{kg}$) flies out tangentially, it was undergoing circular motion under the influence of a centripetal force $F_c$ ($= 20\,\text{N}$). Thus its speed $v$ as it flies out satisfies $F_c = mv^2/R$, where $R = \frac{1}{2}(28\,\text{in.}) = \frac{1}{2}(28\,\text{in.})(0.0254\,\text{m/in.}) = 0.3556\,\text{m}$. So

$$v = \sqrt{\frac{F_c R}{m}} = \sqrt{\frac{(20\,\text{N})(0.3556\,\text{m})}{0.025\,\text{kg}}} = 17\,\text{m/s}.$$

**5.11**

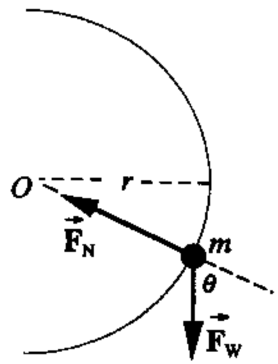
From the figure to the right we see that the bottom of the tube moves in a circle of radius $r = r_1 + l\sin 30° = 5.0\,\text{cm} + (100\,\text{mm})(1\,\text{cm}/10\,\text{mm})(\sin 30°) = 10\,\text{cm} = 0.10\,\text{m}$, at a speed $v = 2\pi r N/t$, where $N = 40\,000$ and $t = 1.0\,\text{min}$. Thus the centripetal acceleration at the bottom of the tube is given by




$$\begin{aligned} a_c &= \frac{v^2}{r} = \frac{(2\pi r N/t)^2}{r} \\ &= \frac{[(2\pi)(0.10\,\text{m})(40\,000)]^2}{(0.10\,\text{m})\,[(1.0\text{min})(60\,\text{s/min})]^2} \\ &= 1.8\times 10^6\,\text{m/s}^2. \end{aligned}$$

**5.13**

The Teddy bear (of mass $m$) is moving in a vertical circle of radius $r$. In addition to its weight, $F_W = mg$, it is also subject to $F_N$, the normal force from the wall of the washer. The net force exerted on the Teddy bear pointing into the center of the circle of radius $R$ in which the Teddy bear moves is then $F_c = F_N - mg\cos\theta$. Let $F_c = mv^2/r$, where $v = 2\pi r/1.0\,\text{s} = 2\pi(0.40\,\text{m})/1.0\,\text{s} = 2.51\,\text{m/s}$, and solve for $F_N$: $F_N = m(v^2/r + g\cos\theta)$. To obtain the maximum value of $F_c$, set $\theta = 0$:




$$F_c(\text{max}) = m\left(\frac{v^2}{r} + g\right) = (4.5\,\text{kg})\left[\frac{(2.51\,\text{m/s})^2}{0.40\,\text{m}} + 9.81\,\text{m/s}^2\right] = 1.2\times 10^2\,\text{N} = 0.12\,\text{kN}.$$

Lacking enough centripetal force to keep them in circular motion, the water drops fly out of the of the drum through the holes, leaving the clothes dry.

**5.17**

This problem is similar to the previous one, with $F_T$ replaced by $F_N$, the normal force exerted on the person by the seat. In this case $r = 100.0\,\text{m}$, $F_W = mg = 800\,\text{N}$, $m = F_W/g = 800\,\text{N}/(9.81\,\text{m/s}^2) = 81.55\,\text{kg}$, and $v = 40.0\,\text{m/s}$. The maximum reading on the scale, which is equal to the value of $F_N$ at the lowest point of the circle, is therefore

$$F_N\,(\text{max}) = F_W + \frac{mv^2}{r} = 800\,\text{N} + \frac{(81.55\,\text{kg})(40.0\,\text{m/s})^2}{100.0\,\text{m}} = 2.10\,\text{kN}\,.$$

**5.18**

Since the car is passing the very peak of the crest we know that the crest must curve downward rather than upward. Similar to Problem (5.15), as the car moves horizontally the centripetal force must be vertical. It is, however, *downward* rather than upward in this case since it has to point toward the center of the circular track in which the car is moving. So, two vertical forces exert on the car: $F_N$, which is upward; and $mg$, downward. Here $m$ is the mass of the car. Let the net *downward* force be equal to $F_c$: $mg - F_N = F_c = mv^2/r$, where $v$ is the speed of the car and $r$ is the radius of curvature. Solve for $F_N$:

$$F_N = m\left(g - \frac{v^2}{r}\right) = (1000\,\text{kg})\left[9.81\,\text{m/s}^2 - \frac{(10.0\,\text{m/s})^2}{50\,\text{m}}\right] = 7.8\times 10^3\,\text{N} = 7.8\,\text{kN}\,.$$

**5.21**

(a) The spin of the space station creates a centripetal acceleration, which simulates gravity. So $a_c = v^2/r = 1.0g$, where $r = \frac{1}{2}(1500\,\text{m}) = 750.0\,\text{m}$ and $v$ is the speed of a point at the periphery. Suppose that the station spins once during time interval $T$, then $v = 2\pi r/T$ (since the distance covered per revolution by a point at the periphery is $2\pi r$). Substitute this expression for $v$ into the equation for $a_c$: $a_c = (2\pi r/T)^2/r = 1.0g$. Solve for $T$:

$$T = 2\pi\sqrt{\frac{r}{1.0g}} = 2\pi\sqrt{\frac{750.0\,\text{m}}{1.0(9.81\,\text{m/s}^2)}} = 55\,\text{s}\,,$$

i.e., the spin rate is $1\,\text{rev}/55\,\text{s} = 0.018\,\text{rev/s}$.

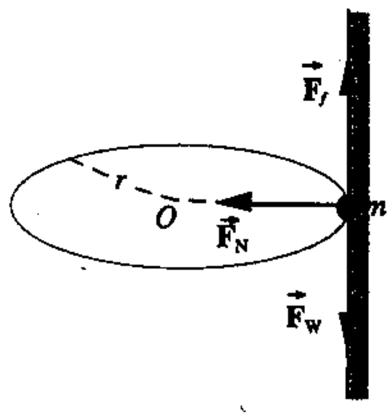
(b) From part (a) above we see that

$$a_c = \frac{(2\pi r/T)^2}{r} \propto r\,,$$

so the simulated gravity, which is equal to $a_c$, is directly proportional to $r$, decreasing linearly with the distance "up" from the floor.

**5.24**

The forces exerted on the person of mass $m$ pressed against the vertical wall of the cylinder are shown to the right. The acceleration of the person is horizontal, so there is no net external force in the vertical direction:




$$+\!\uparrow\sum F_y = F_f - F_W = ma_y = 0\,,$$

where $F_W = mg$ is the weight of the person. Horizontally,

$$a_x = a_c = \frac{v^2}{r} = \frac{1}{r}\left(\frac{2\pi r}{T}\right)^2 = \frac{4\pi^2 r}{T^2}\,,$$

where $r$ is the radius of the cylinder, $T$ is the time it takes for the cylinder to complete one revolution, and $v = 2\pi r/T$ is the speed of the person in circular motion. Then Newton's Second Law requires that

$$\overset{+}{\leftarrow}\sum F_x = F_N = ma_x = \frac{4\pi^2 mr}{T^2},$$

or $r = F_N T^2/4\pi^2 m$. Now, Since $F_W = mg = F_f \leq \mu_s F_N$, $F_N \geq mg/\mu_s$. Substitute this expression for $F_N$ into the previous equation for $r$ to obtain

$$r = \frac{F_N T^2}{4\pi^2 m} \geq \left(\frac{mg}{\mu_s}\right)\left(\frac{T^2}{4\pi^2 m}\right) = \frac{gT^2}{4\pi^2 \mu_s}.$$

Since the cylinder is to turn at least at $\frac{1}{2}$ rev/s, the maximum value of $T$ is $T_{max} = 2.0\,\mathrm{s}$. To operate the ride safely, the inequality we obtained above for $r$ is to be valid for *any* value of $T$, up to $T_{max}$. So we must have

$$r \geq \frac{gT_{max}{}^2}{4\pi^2 \mu_s} = \frac{(9.81\,\mathrm{m/s^2})(2.0\,\mathrm{s})^2}{4\pi^2(0.20)} = 4.97\,\mathrm{m},$$

and the corresponding diameter is $D = 2r = 9.9\,\mathrm{m}$.