5.24

Var	Given value	Units	Description
F		N	Force of gravity
G	6.673×10^{-11}	$\frac{\mathrm{m}^3}{\mathrm{kg\ s}^2}$	Universal gravitational constant
m_1	0.20	kg	Mass of apple
m_{earth}	5.98×10^{24}	kg	Mass of the earth
r_{earth}	6.38×10^{6}	m	Radius of the earth
a		$\frac{\mathrm{m}}{\mathrm{s}^2}$	acceleration of apple

$$F = G\frac{m_1\, m_{\mathrm{earth}}}{r_{\mathrm{earth}}{}^2}$$

$$= \left(6.673\times10^{-11}\ \frac{\mathrm{m}^3}{\mathrm{kg\,s}^2}\right)\frac{(0.20\,\mathrm{kg})(5.98\times10^{24}\,\mathrm{kg})}{(6.38\times10^{6}\,\mathrm{m})^2}$$

$$= 2.0\,\mathrm{N} \quad ✓$$

From the reference frame of the earth, the net force on the apple is –2.0 N. This gives an acceleration of

$$a = \frac{-F}{m_1}$$

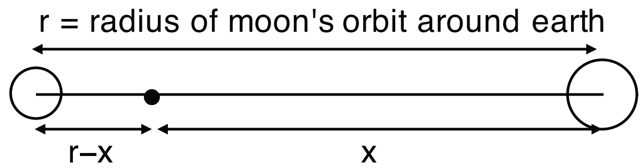
$$= \frac{-2.0\,\mathrm{N}}{0.20\,\mathrm{kg}}$$

$$= -10.\ \frac{\mathrm{m}}{\mathrm{s}^2} \quad ✓$$

5.24 (continued)

The earth accelerates towards the apple at 10. $\frac{m}{s^2}$ (from the reference frame of the apple).

5.26



x = dist. of space ship to earth
r–x = dist. of space ship to moon

Var	Given value	Units	Description
$F_{ship,moon}$		N	force of grav. between ship and moon
$F_{ship,earth}$		N	force of grav. between ship and earth
G	6.673×10^{-11}	$\frac{m^3}{kg\ s^2}$	Universal gravitational constant
r		m	radius of moon's orbit
m_{moon}	$0.0123 m_{earth}$		mass of moon
m_{earth}		kg	Mass of the earth
m_{ship}		kg	mass of space ship
x		m	dist. of space ship to moon

$$F_{ship,moon} = G \frac{m_{moon}\, m_{ship}}{(r - x)^2}$$

5.26 (continued)

$$F_{\text{ship,earth}} = G\frac{m_{\text{earth}}\, m_{\text{ship}}}{x^2}$$

$$F_{\text{ship,moon}} = F_{\text{ship,earth}}$$

$$G\frac{m_{\text{moon}}\, m_{\text{ship}}}{(r-x)^2} = G\frac{m_{\text{earth}}\, m_{\text{ship}}}{x^2}$$

$$\sqrt{\frac{0.0123\, m_{\text{earth}}}{(r-x)^2}} = \sqrt{\frac{m_{\text{earth}}}{x^2}}$$

$$\frac{0.1109}{r-x} = \frac{1}{x}$$

$$0.1109\, x = r - x$$

$$1.1109\, x = r$$

$$x = \frac{r}{1.1109} = 0.90\, r$$

5.32a

Var	Given value	Units	Description
m_{saturn}	95 m_{earth}	kg	mass of saturn
m_{earth}		kg	mass of earth
r_{saturn}	9.0 r_{earth}	m	radius of saturn
r_{earth}		m	radius of earth
G	6.673×10^{-11}	$\frac{m^3}{kg\ s^2}$	Universal gravitational constant
g_{saturn}		$\frac{m}{s^2}$	acc. due to gravity on saturn
g_{earth}		$\frac{m}{s^2}$	acc. due to gravity on earth
m		kg	mass of object on surface of planet

$$m\, g_{saturn} = G \frac{m\, m_{saturn}}{r_{saturn}^{2}}$$

$$g_{saturn} = G \frac{m_{saturn}}{r_{saturn}^{2}}$$

$$g_{saturn} = G \frac{95\, m_{earth}}{(9.0\, r_{earth})^{2}} = \left(\frac{95}{9.0^{2}}\right)\left(G \frac{m_{earth}}{r_{earth}^{2}}\right)$$

$$g_{earth} = G \frac{m_{earth}}{r_{earth}^{2}}$$

5.32a (continued)

$$g_{\text{saturn}} = \frac{95}{9.0^{2}}\, g_{\text{earth}}$$

$$g_{\text{saturn}} = 1.2\, g_{\text{earth}}$$

5.34

Var	Given value	Units	Description
F	1.53×10^{-7}	N	Force of gravity
G		$\frac{\mathrm{m}^3}{\mathrm{kg\,s}^2}$	Universal gravitational constant
m_1	0.730	kg	Mass of body 1
m_2	158	kg	Mass of body 2
r	0.225	m	Distance between the masses

$$F = G\frac{m_1 m_2}{r^2}$$

$$G = \frac{F r^2}{m_1 m_2}$$

$$= \frac{\left(1.53\times10^{-7}\,\mathrm{N}\right)(0.225\,\mathrm{m})^2}{(0.730\,\mathrm{kg})(158\,\mathrm{kg})}$$

$$= 6.72\times10^{-11}\,\frac{\mathrm{m}^3}{\mathrm{kg\,s}^2}$$

5.36

Var	Given value	Units	Description
F_g		N	Force of gravity between satellite and earth
G	6.673×10^{-11}	$\frac{m^3}{kg\ s^2}$	Universal gravitational constant
r_{orbit}		m	radius of satellite's orbit
m		kg	Mass of satellite
m_{earth}	5.98×10^{24}	kg	Mass of earth
F_c		N	Centripetal force on satellite
T		s	Period of satellite
$r_{moonorbit}$	3.84×10^{8}	m	radius of moon's orbit

$$r_{orbit} = \left(\frac{1}{3}\right) r_{moonorbit}$$

$$= \left(\frac{1}{3}\right)\left(3.84 \times 10^{8}\ \mathrm{m}\right)$$

$$= 1.28 \times 10^{8}\ \mathrm{m}$$

5.36 (continued)

$$F_g = G\frac{m\,m_{earth}}{r_{orbit}{}^2}$$

$$F_c = \frac{m\,4\,\pi^2\,r_{orbit}}{T^2}$$

$$F_g = F_c$$

$$G\frac{m\,m_{earth}}{r_{orbit}{}^2} = \frac{m\,4\,\pi^2\,r_{orbit}}{T^2}$$

$$G\frac{m_{earth}}{r_{orbit}{}^2} = \frac{4\,\pi^2\,r_{orbit}}{T^2}$$

$$T^2 = \frac{4\,\pi^2\,r_{orbit}{}^3}{G\,m_{earth}}$$

$$T = \sqrt{\frac{4\,\pi^2\,r_{orbit}{}^3}{G\,m_{earth}}}$$

$$= \sqrt{\frac{4\,\pi^2\left(1.28\times10^{8}\,\mathrm{m}\right)^3}{\left(6.673\times10^{-11}\,\frac{\mathrm{m}^3}{\mathrm{kgs}^2}\right)\left(5.98\times10^{24}\,\mathrm{kg}\right)}}$$

$$= 4.55\times10^{5}\,\mathrm{s}$$ ✓

5.38

Var	Given value	Units	Description
F_g		N	Force of gravity between venus and sun
G	6.673×10^{-11}	$\frac{m^3}{kg\ s^2}$	Universal gravitational constant
r	1.08×10^{11}	m	radius of venus' orbit
m		kg	Mass of venus
m_{sun}	1.99×10^{30}	kg	Mass of the sun
F_c		N	Centripetal force on venus
T		s	Period of venus

$$F_g = F_c$$

$$G\frac{m\,m_{sun}}{r^2} = \frac{m\,4\,\pi^2\,r}{T^2}$$

$$G\frac{m_{sun}}{r^2} = \frac{4\,\pi^2\,r}{T^2}$$

$$T^2\,G\frac{m_{sun}}{r^2} = 4\,\pi^2\,r$$

$$T^2 = \frac{4\,\pi^2\,r}{G\frac{m_{sun}}{r^2}}$$

5.38 (continued)

$$T = \sqrt{\frac{4\pi^2 r}{G\frac{m_{sun}}{r^2}}}$$

$$= \sqrt{\frac{4\pi^2 (1.08\times10^{11}\,\mathrm{m})}{\left(6.673\times10^{-11}\,\frac{\mathrm{m}^3}{\mathrm{kgs}^2}\right)\frac{1.99\times10^{30}\,\mathrm{kg}}{(1.08\times10^{11}\,\mathrm{m})^2}}}$$

$$= 1.94\times10^{7}\,\mathrm{s}$$

5.40

In order for a satellite's orbit to remain stationary above the same location on Earth, the satellite's orbital period (the time required for one complete orbit) needs to equal the Earth's rotational period – one day. Because the satellite orbits at the same rate the Earth rotates, the satellite remains stationary above the same longitude on Earth.

In addition for the satellite orbit to be truly geostationary, the orbit must not be inclined to the equator. Otherwise the satellite will oscillate in a north south direction above the same longitude.

Var	Given value	Units	Description
F_g		N	Force of gravity between satellite and earth
G	6.673×10^{-11}	$\frac{m^3}{kg\ s^2}$	Universal gravitational constant
r_{orbit}		m	radius of satellite's orbit
m		kg	Mass of satellite
m_{earth}	5.98×10^{24}	kg	Mass of earth
F_c		N	Centripetal force on satellite
T	86400	s	Period of satellite

$$F_g = F_c$$

$$G \frac{m\, m_{earth}}{r_{orbit}^{\ 2}} = \frac{m\, 4\, \pi^2\, r_{orbit}}{T^2}$$

$$G \frac{m_{earth}}{r_{orbit}^{\ 2}} = \frac{4\, \pi^2\, r_{orbit}}{T^2}$$

$$T^2\, G\, m_{earth} = 4\, \pi^2\, r_{orbit}^{\ 3}$$

5.40 (continued)

$$\frac{T^2 G m_{\text{earth}}}{4\pi^2} = r_{\text{orbit}}^{\;3}$$

$$r_{\text{orbit}} = \left(\frac{T^2 G m_{\text{earth}}}{4\pi^2}\right)^{\frac{1}{3}}$$

$$= \left(\frac{(86400\,\text{s})^2\left(6.673\times10^{-11}\,\frac{\text{m}^3}{\text{kgs}^2}\right)\left(5.98\times10^{24}\,\text{kg}\right)}{4\pi^2}\right)^{\frac{1}{3}}$$

$$= 4.23\times10^{7}\ \text{m}$$

5.44

Var	Given value	Units	Description
F_g		N	Force of gravity
G	6.673×10^{-11}	$\frac{m^3}{kg\,s^2}$	Universal gravitational constant
m_{moon}	7.35×10^{22}	kg	Mass of moon
m_{earth}	5.98×10^{24}	kg	Mass of the earth
r	3.84×10^{8}	m	Distance between centers of earth and moon
F_c		N	centripetal force on moon
v		$\frac{m}{s}$	speed of moon

$$F_g = G\frac{m_{moon}\,m_{earth}}{r^2}$$

$$= \left(6.673\times10^{-11}\ \frac{m^3}{kg\,s^2}\right)\frac{(7.35\times10^{22}\ kg)(5.98\times10^{24}\ kg)}{(3.84\times10^{8}\ m)^2}$$

$$= 1.99\times10^{20}\ N \quad \checkmark$$

$$F_c = F_g$$

$$= 1.99\times10^{20}\ N \quad \checkmark$$

5.44 (continued)

$$F_c = m_{\text{moon}} \frac{v^2}{r}$$

$$v = \sqrt{\frac{F_c}{m_{\text{moon}}} r}$$

$$= \sqrt{\frac{1.99\times10^{20}\,\text{N}}{7.35\times10^{22}\,\text{kg}}\left(3.84\times10^{8}\,\text{m}\right)}$$

$$= 1.02\times10^{3}\,\frac{\text{m}}{\text{s}}$$

5.46

Var	Given value	Units	Description
F_g		N	Force of gravity between tank and moon or weight of tank on moon
G	6.673×10^{-11}	$\frac{m^3}{kg\ s^2}$	Universal gravitational constant
m_{tank}	25	kg	Mass of tank
m_{moon}		kg	Mass of moon
m_{earth}		kg	mass of earth
r_{moon}		m	radius of moon
r_{earth}		m	radius of earth
g_{earth}	9.80	$\frac{m}{s^2}$	acc. due to grav. on earth

$$r_{moon} = 0.273\, r_{earth}$$

$$m_{moon} = 0.0123\, m_{earth}$$

$$F_g = G\frac{m_{tank}\, m_{moon}}{r_{moon}^{\;2}}$$

$$F_g = G\frac{m_{tank}\, 0.0123\, m_{earth}}{(0.273\, r_{earth})^2}$$

$$F_g = \left(\frac{0.0123}{(0.273)^2}\, m_{tank}\right)\left(G\frac{m_{earth}}{r_{earth}^{\;2}}\right)$$

5.46 (continued)

$$g_{\text{earth}} = G\frac{m_{\text{earth}}}{r_{\text{earth}}^{2}}$$

$$F_{\text{g}} = \frac{0.0123}{(0.273)^{2}}\, m_{\text{tank}}\, g_{\text{earth}}$$

$$= \frac{0.0123}{(0.273)^{2}}(25\,\text{kg})\left(9.80\,\frac{\text{m}}{\text{s}^{2}}\right)$$

$$= 40.4\,\text{N}$$ ✓

5.48

Var	Given value	Units	Description
r_{earth}	6378132.1	m	Radius of the earth
d	91.4	m	height of object above surface
$F_{surface}$		N	Force of gravity on object at earth's surface
F		N	Force of gravity on object at 91.4 m above surface
G	6.673×10^{-11}	$\frac{m^3}{kg\ s^2}$	Universal gravitational constant
m		kg	Mass of object
m_{earth}	5.98×10^{24}	kg	Mass of the earth
ΔW			fractional change in weight

$$F_{surface} = G\frac{m\,m_{earth}}{r_{earth}^{2}}$$

$$F = G\frac{m\,m_{earth}}{(r_{earth}+d)^{2}}$$

$$\Delta W = \frac{F_{surface}-F}{F_{surface}}$$

$$\Delta W = \frac{\frac{1}{r_{earth}^{2}}-\frac{1}{(r_{earth}+d)^{2}}}{\frac{1}{r_{earth}^{2}}}$$

$$= \frac{\frac{1}{(6378132.1m)^{2}}-\frac{1}{((6378132.1m)+(91.4m))^{2}}}{\frac{1}{(6378132.1m)^{2}}}$$

5.48 (continued)

$$= 2.87\times10^{-5}$$ ✓