Section 6.2: Orbits

Mini Investigation: Exploring Gravity and Orbits, page 298

A. When I increase the size of the Sun, Earth's orbit changes: the orbit is closer to the Sun.
B. The Moon is pulled out of Earth's orbit and orbits the Sun. When you increase the size of Earth, the Moon orbits closer and faster.
C. The orbital radius and orbital period decrease.
D. Answers may vary. Students should describe a system using the satellite and planet simulation that includes a gravity assist by having the satellite use the planet's gravity to change direction. The scale is too small to notice changes in speed.

Tutorial 1 Practice, page 302

1. Given: $r = 5.34 \times 10^{17}$ m; $v = 7.5 \times 10^{5}$ m/s; $G = 6.67 \times 10^{-11}$ N·m²/kg²
Required: m
Analysis: Rearrange the equation for speed to solve for mass:

$$v = \sqrt{\frac{Gm}{r}}$$

$$v^2 = \frac{Gm}{r}$$

$$m = \frac{rv^2}{G}$$

Solution: $m = \dfrac{rv^2}{G}$

$$= \frac{\left(5.34 \times 10^{17}\ \cancel{\text{m}}\right)\left(7.5 \times 10^{5}\ \cancel{\text{m}}/\cancel{\text{s}}\right)^2}{6.67 \times 10^{-11}\ \dfrac{\cancel{\text{kg}} \cdot \dfrac{\cancel{\text{m}}}{\cancel{\text{s}^2}} \cdot \cancel{\text{m}^2}}{\text{kg}^{\cancel{2}}}}$$

$$m = 4.5 \times 10^{39}\ \text{kg}$$

Statement: The mass of the black hole is 4.5×10^{39} kg.

2. Given: $r = 2.28 \times 10^{11}$ m; $m = 6.42 \times 10^{23}$ kg; $F_g = 1.63 \times 10^{21}$ N; $m_{Sun} = 1.99 \times 10^{30}$ kg; $G = 6.67 \times 10^{-11}$ N·m²/kg²
Required: v; T
Analysis: $v = \sqrt{\dfrac{Gm}{r}}$; $T = \dfrac{2\pi r}{v}$

Solution: Determine the orbital speed of Mars:

$$v = \sqrt{\frac{Gm_{\text{Sun}}}{r}}$$

$$= \sqrt{\frac{\left(6.67\times10^{-11}\ \frac{\text{kg}\cdot\frac{\text{m}}{\text{s}^2}\cdot\text{m}^2}{\text{kg}^2}\right)\left(1.99\times10^{30}\ \text{kg}\right)}{2.28\times10^{11}\ \text{m}}}$$

$$= 2.4128\times10^{4}\ \text{m/s (two extra digits carried)}$$

$$v = 2.41\times10^{4}\ \text{m/s}$$

Determine the period:

$$T = \frac{2\pi r}{v}$$

$$= \frac{2\pi\left(2.28\times10^{11}\ \text{m}\right)}{2.4128\times10^{4}\ \frac{\text{m}}{\text{s}}}$$

$$= 5.937\times10^{7}\ \text{s}\times\frac{1\ \text{min}}{60\ \text{s}}\times\frac{1\ \text{h}}{60\ \text{min}}\times\frac{1\ \text{d}}{24\ \text{h}}\times\frac{1\ \text{y}}{365\ \text{d}}$$

$$T = 1.90\ \text{y}$$

Statement: The speed of Mars is 2.41×10^4 m/s, and its period is 1.90 Earth years.

3. Given: $d = 600.0$ km $= 6.000 \times 10^5$ m; $r_E = 6.38 \times 10^6$ m; $m_E = 5.98 \times 10^{24}$ kg; $G = 6.67 \times 10^{-11}$ N·m^2/kg^2

Required: v; T

Analysis: Determine the orbital radius, then use the value for r to calculate the speed, $v = \sqrt{\frac{Gm}{r}}$.

Then use the equation for period, $T = \frac{2\pi r}{v}$.

$$r = d + r_{\text{E}}$$

$$= 6.000\times10^{5}\ \text{m} + 6.38\times10^{6}\ \text{m}$$

$$r = 6.98\times10^{6}\ \text{m}$$

Solution:

$$v = \sqrt{\frac{Gm}{r}}$$

$$= \sqrt{\frac{(6.67\times10^{-11}\ \text{N}\cdot\text{m}^2/\text{kg}^2)(5.98\times10^{24}\ \text{kg})}{6.98\times10^{6}\ \text{m}}}$$

$$v = 7.559\times10^{3}\ \text{m/s (one extra digit carried)}$$

$$T = \frac{2\pi r}{v}$$
$$= \frac{2\pi(6.98 \times 10^6 \cancel{\text{m}})}{7.559 \times 10^3 \ \cancel{\text{m}}/\text{s}}$$
$$= 5801.9 \ \cancel{\text{s}} \times \frac{1 \text{ min}}{60 \ \cancel{\text{s}}}$$
$$T = 97 \text{ min}$$

Statement: The speed of the satellite is 7.56×10^3 m/s, and the period of the satellite is 97 min.

4. Given: d = 25 m; $r_{\text{Moon}} = 1.74 \times 10^6$ m; $m = 7.36 \times 10^{22}$ kg; $G = 6.67 \times 10^{-11}$ N·m^2/kg^2

Required: v

Analysis: $v = \sqrt{\frac{Gm}{r}}$

Solution: Determine the orbital radius:

$$r = d + r_{\text{Moon}}$$
$$= 25 \text{ m} + 1.74 \times 10^6 \text{ m}$$
$$r = 1.740 \times 10^6 \text{ m}$$

Determine the orbital speed:

$$v = \sqrt{\frac{Gm}{r}}$$
$$= \sqrt{\frac{\left(6.67 \times 10^{-11} \ \frac{\cancel{\text{kg}} \cdot \frac{\cancel{\text{m}}}{\text{s}^2} \cdot \text{m}^2}{\cancel{\text{kg}^2}}\right)\left(7.36 \times 10^{22} \ \cancel{\text{kg}}\right)}{1.740 \times 10^6 \ \cancel{\text{m}}}}$$
$$v = 1.7 \times 10^3 \text{ m/s}$$

Statement: The orbital speed of the satellite is 1.7×10^3 m/s.

Research This: Space Junk, page 302

A. Air resistance will slow a satellite and cause it to slip into a lower orbit.

B. The satellite may hit other satellites or burn up in the atmosphere.

C. Sample answer: Yes. Different styles of rockets and boosters are being considered for space missions. Another way to reduce space junk is to equip satellites with small boosters that would enable them to fall to Earth once they have become obsolete.

D. Sample answer: Space junk is regularly falling to Earth. To speed up the removal of space junk, specific missions to remove space junk can be undertaken. A proposed technology that could help reduce the amount of space junk is a “laser broom.” A laser broom is a ground-based laser beam that would heat space junk enough to cause it to break apart into much smaller pieces or change direction and fall to Earth.

E. Answers may vary. Sample answer:
Hi Amelia;

I was researching the Internet and found out that space junk is actually many types of debris. According to the NASA Orbital Debris Space Program Office space junk is

- abandoned spacecraft or spacecraft parts that no longer work—these items float around in space circling Earth until they fall back down or collide with other space junk
- upper stages of launch vehicles—these are parts of space shuttles that are fired off or ejected in stages, usually the upper parts of the rocket which get ejected last and are trapped in Earth's orbit
- solid rocket fuel—some space shuttles use solid rocket fuel for propulsion and some can be left over after launch in the container in which it was sent up
- tiny flecks of paint—when spacecraft enters space, heat or collisions with small particles chip paint from the surface of the spacecraft

I find it interesting that paint flecks are considered space junk, and despite their size they can actually do quite a bit of damage when they strike objects. Space junk can orbit Earth at a speed of more than 3.5×10^4 km/h. If a speck of paint travelling at that speed hits a space station, it can create a 0.6 cm diameter hole in the window of the space station. Hard to believe something that small can cause a lot of damage!

Section 6.2 Questions, page 303

1. Natural satellites are natural objects that revolve around another body due to gravitational attraction, such as the Moon in the Earth–Moon system. Artificial satellites are objects that have been manufactured and intentionally placed in orbit by humans, such as the International Space Station.
2. Microgravity is a more accurate term than "zero gravity" to describe what astronauts experience on the International Space Station. Microgravity is one millionth the value of g.
3. GPS satellites are a network of 24 satellites that coordinate several of their signals at once to locate objects on Earth's surface.
4. (a) A geosynchronous orbit is an orbit at a location above Earth's surface such that the speed of an object in a geosynchronous orbit matches the rate of the Earth's rotation.
(b) A satellite in geosynchronous orbit appears to pass through the same position in the sky at the same time every day to an observer on Earth.
(c) A satellite in a geostationary orbit appears to remain in the same position in the sky to an observer on Earth.
5. Given: $T = 24$ h; $m_E = 5.98 \times 10^{24}$ kg; $G = 6.67 \times 10^{-11}$ N·m^2/kg^2
Required: r

Analysis: Use the equation for period to isolate v, $T = \frac{2\pi r}{v}$. Then set the value for v equal to the equation for v to isolate and solve for r, $v = \sqrt{\frac{Gm}{r}}$.

But first convert 24 h to seconds:

$$T = \frac{24\ \cancel{\text{h}}}{1\ \cancel{\text{d}}} \times \frac{60\ \cancel{\text{min}}}{1\ \cancel{\text{h}}} \times \frac{60\ \text{s}}{1\ \cancel{\text{min}}}$$

$$T = 86\ 400\ \text{s}$$

$$T = \frac{2\pi r}{v}$$

$$v = \frac{2\pi r}{T}$$

$$\sqrt{\frac{Gm}{r}} = \frac{2\pi r}{T}$$

$$\frac{Gm}{r} = \frac{4\pi^2 r^2}{T^2}$$

$$\frac{GmT^2}{4\pi^2} = r^3$$

Solution: $\frac{GmT^2}{4\pi^2} = r^3$

$$r^3 = \frac{\left(6.67 \times 10^{-11}\ \frac{\cancel{\text{kg}} \cdot \frac{\cancel{\text{m}}}{\cancel{\text{s}^2}} \cdot \text{m}^{\cancel{2}}}{\cancel{\text{kg}^2}}\right)\left(5.98 \times 10^{24}\ \cancel{\text{kg}}\right)\left(86\,400\ \cancel{\text{s}}\right)^{\cancel{2}}}{4\pi^2}$$

$$r = 4.2 \times 10^7\ \text{m}$$

Statement: The orbital radius of a satellite in geosynchronous orbit is 4.2×10^7 m.

6. (a) Given: $T = 164.5$ y; $r = 4.5 \times 10^9$ km $= 4.5 \times 10^{12}$ m

Required: v

Analysis: Use the equation for period to isolate and solve for v, $T = \frac{2\pi r}{v}$. But first convert the period to seconds:

$$T = 164.5\ \cancel{\text{y}} \times \frac{365\ \cancel{\text{d}}}{1\ \cancel{\text{y}}} \times \frac{24\ \cancel{\text{h}}}{1\ \cancel{\text{d}}} \times \frac{60\ \cancel{\text{min}}}{1\ \cancel{\text{h}}} \times \frac{60\ \text{s}}{1\ \cancel{\text{min}}}$$

$T = 5.188 \times 10^9$ s (two extra digits carried)

$$T = \frac{2\pi r}{v}$$

$$v = \frac{2\pi r}{T}$$

Solution: Determine the orbital speed of Neptune:

$$v = \frac{2\pi r}{T}$$

$$= \frac{2\pi(4.5\times10^{12}\ \text{m})}{5.188\times10^{9}\ \text{s}}$$

$$= 5.450\times10^{3}\ \text{m/s (two extra digits carried)}$$

$$v = 5.5\times10^{3}\ \text{m/s}$$

Statement: The orbital speed of Neptune is 5.5×10^3 m/s.
(b) Given: $r = 4.5 \times 10^9$ km $= 4.5 \times 10^{12}$ m; $v = 5.450 \times 10^3$ m/s;
$G = 6.67 \times 10^{-11}$ N·m^2/kg^2
Required: m

Analysis: Use the equation for speed to isolate and solve for m, $v = \sqrt{\frac{Gm}{r}}$:

$$v = \sqrt{\frac{Gm}{r}}$$

$$v^2 = \frac{Gm}{r}$$

$$m = \frac{rv^2}{G}$$

Solution: $m = \frac{rv^2}{G}$

$$= \frac{(4.5\times10^{12}\ \cancel{\text{m}})(5.450\times10^{3}\ \cancel{\text{m/s}})^2}{6.67\times10^{-11}\ \frac{\cancel{\text{kg}}\cdot\frac{\cancel{\text{m}}}{\cancel{\text{s}^2}}\cdot\cancel{\text{m}^2}}{\text{kg}^{\cancel{2}}}}$$

$$m = 2.0\times10^{30}\ \text{kg}$$

Statement: The mass of the Sun is 2.0×10^{30} kg.
7. Given: $T = 29$ y; $v = 9.69$ km/s $= 9.69 \times 10^3$ m/s
Required: r

Analysis: $T = \frac{2\pi r}{v}$, but first convert the period to seconds:

$$T = 29\ \cancel{\text{y}} \times \frac{365\ \cancel{\text{d}}}{1\ \cancel{\text{y}}} \times \frac{24\ \cancel{\text{h}}}{1\ \cancel{\text{d}}} \times \frac{60\ \cancel{\text{min}}}{1\ \cancel{\text{h}}} \times \frac{60\ \text{s}}{1\ \cancel{\text{min}}}$$

$$= 9.145\times10^{8}\ \text{s (two extra digits carried)}$$

$$T = 9.1\times10^{8}\ \text{s}$$

Solution: Determine the orbital radius of Saturn:

$$T = \frac{2\pi r}{v}$$

$$r = \frac{Tv}{2\pi}$$

$$= \frac{(9.145 \times 10^8 \text{ s})(9.69 \times 10^3 \text{ m/s})}{2\pi}$$

$$r = 1.4 \times 10^{12} \text{ m}$$

Statement: The orbital radius of Saturn is 1.4×10^{12} m.

8. (a) Given: $r = 5.03 \times 10^{11}$ m; $m_{\text{Sun}} = 1.99 \times 10^{30}$ kg; $G = 6.67 \times 10^{-11}$ N·m²/kg²

Required: v

Analysis: $v = \sqrt{\dfrac{Gm}{r}}$

Solution: $v = \sqrt{\dfrac{Gm}{r}}$

$$= \sqrt{\frac{\left(6.67 \times 10^{-11} \dfrac{\cancel{\text{kg}} \cdot \dfrac{\cancel{\text{m}}}{\text{s}^2} \cdot \text{m}^2}{\text{kg}^{\cancel{2}}}\right)(1.99 \times 10^{30} \cancel{\text{kg}})}{5.03 \times 10^{11} \cancel{\text{m}}}}$$

$$= 1.6244 \times 10^4 \text{ m/s (two extra digits carried)}$$

$$v = 1.62 \times 10^4 \text{ m/s}$$

Statement: The speed of the asteroid is 1.62×10^4 m/s.

(b) Given: $r = 5.03 \times 10^{11}$ m; $v = 1.6244 \times 10^4$ m/s

Required: T

Analysis: $T = \dfrac{2\pi r}{v}$

Solution: $T = \dfrac{2\pi r}{v}$

$$= \frac{2\pi(5.03 \times 10^{11} \cancel{\text{m}})}{1.6244 \times 10^4 \dfrac{\cancel{\text{m}}}{\text{s}}}$$

$$= 1.9456 \times 10^8 \cancel{\text{s}} \times \frac{1 \cancel{\text{min}}}{60 \cancel{\text{s}}} \times \frac{1 \cancel{\text{h}}}{60 \cancel{\text{min}}} \times \frac{1 \cancel{\text{d}}}{24 \cancel{\text{h}}} \times \frac{1 \text{ y}}{365 \cancel{\text{d}}}$$

$$T = 6.17 \text{ y}$$

Statement: The period of the asteroid is 6.17 y.

9. Given: $m = 1.99 \times 10^{30}$ kg; $r = 4.05 \times 10^{12}$ m; $G = 6.67 \times 10^{-11}$ N·m²/kg²

Required: v

Analysis: $v = \sqrt{\dfrac{Gm}{r}}$

Solution: $v = \sqrt{\frac{Gm}{r}}$

$$= \sqrt{\frac{\left(6.67 \times 10^{-11}\ \frac{\cancel{\text{kg}} \cdot \frac{\cancel{\text{m}}}{\text{s}^2} \cdot \text{m}^2}{\cancel{\text{kg}^2}}\right)\left(1.99 \times 10^{30}\ \cancel{\text{kg}}\right)}{4.05 \times 10^{12}\ \cancel{\text{m}}}}$$

$$= 5725.8\ \frac{\cancel{\text{m}}}{\cancel{\text{s}}} \times \frac{60\ \cancel{\text{s}}}{1\ \cancel{\text{min}}} \times \frac{60\ \cancel{\text{min}}}{1\ \text{h}} \times \frac{1\ \text{km}}{1000\ \cancel{\text{m}}}$$

$$v = 2.06 \times 10^4\ \text{km/h}$$

Statement: The orbital speed of the exoplanet is 2.06×10^4 km/h.

10. Given: $r = 4.03 \times 10^{11}$ m; $T = 1100$ d; $G = 6.67 \times 10^{-11}\ \text{N}{\cdot}\text{m}^2/\text{kg}^2$

Required: m

Analysis: Use the equation for T to isolate and then solve for v, $T = \frac{2\pi r}{v}$. Then use the equation for speed to isolate and solve for m, $v = \sqrt{\frac{Gm}{r}}$. But first, convert the period to seconds:

$$T = 1100\ \cancel{\text{d}} \times \frac{24\ \cancel{\text{h}}}{1\ \cancel{\text{d}}} \times \frac{60\ \cancel{\text{min}}}{1\ \cancel{\text{h}}} \times \frac{60\ \text{s}}{1\ \cancel{\text{min}}}$$

$T = 9.504 \times 10^7$ s (two extra digits carried)

$$T = \frac{2\pi r}{v}$$

$$v = \frac{2\pi r}{T}$$

$$v = \sqrt{\frac{Gm}{r}}$$

$$v^2 = \frac{Gm}{r}$$

$$m = \frac{rv^2}{G}$$

Solution: Determine the orbital speed of the exoplanet:

$$v = \frac{2\pi r}{T}$$

$$= \frac{2\pi\left(4.03 \times 10^{11}\ \text{m}\right)}{9.504 \times 10^7\ \text{s}}$$

$v = 2.664 \times 10^4$ m/s (two extra digits carried)

Determine the mass of the star:

$$m = \frac{rv^2}{G}$$

$$= \frac{(4.03\times10^{11}\ \text{m})\left(2.664\times10^{4}\ \frac{\text{m}}{\text{s}}\right)^2}{6.67\times10^{-11}\ \frac{\text{kg}\cdot\frac{\text{m}}{\text{s}^2}\cdot\text{m}^2}{\text{kg}^2}}$$

$$m = 4.3\times10^{30}\ \text{kg}$$

Statement: The mass of the star is 4.3×10^{30} kg.

11. Given: $r = 9.38 \times 10^6$ m; $m = 6.42 \times 10^{23}$ kg; $G = 6.67 \times 10^{-11}$ N·m²/kg²

Required: T

Analysis: Use the equation for period, $T = \frac{2\pi r}{v}$. For v in the equation for period, use $v = \sqrt{\frac{Gm}{r}}$.

$$T = \frac{2\pi r}{v}$$

$$= \frac{2\pi r}{\sqrt{\frac{Gm}{r}}}$$

$$T = \frac{2\pi\sqrt{r^3}}{\sqrt{Gm}}$$

Solution: $T = \frac{2\pi\sqrt{r^3}}{\sqrt{Gm}}$

$$= \frac{2\pi\sqrt{(9.38\times10^{6}\ \text{m})^3}}{\sqrt{\left(6.67\times10^{-11}\ \frac{\text{kg}\cdot\frac{\text{m}}{\text{s}^2}\cdot\text{m}^2}{\text{kg}^2}\right)(6.42\times10^{23}\ \text{kg})}}$$

$$= 27\,584\ \text{s}\times\frac{1\ \text{min}}{60\ \text{s}}\times\frac{1\ \text{h}}{60\ \text{min}}\times\frac{1\ \text{d}}{24\ \text{h}}$$

$$T = 0.319\ \text{d}$$

Statement: The period of Phobos is 0.319 days.

12. Given: $T = 24$ h; $m_E = 5.98 \times 10^{24}$ kg; $G = 6.67 \times 10^{-11}$ N·m²/kg²

Required: v

Analysis: Using the equations for period and speed, isolate r in each: $T = \frac{2\pi r}{v}$, $v = \sqrt{\frac{Gm}{r}}$. Then set the two equations equal to each other and solve for v.

But first convert 24 h to seconds:

$$T = \frac{24\ \text{h}}{1\ \text{d}} \times \frac{60\ \text{min}}{1\ \text{h}} \times \frac{60\ \text{s}}{1\ \text{min}}$$

$$T = 86\ 400\ \text{s}$$

$$T = \frac{2\pi r}{v} \qquad v = \sqrt{\frac{Gm}{r}}$$

$$r = \frac{Tv}{2\pi} \qquad v^2 = \frac{Gm}{r}$$

$$r = \frac{Gm}{v^2}$$

$$\frac{Tv}{2\pi} = \frac{Gm}{v^2}$$

$$v^3 = \frac{2\pi Gm}{T}$$

Solution:

$$\frac{Tv}{2\pi} = \frac{Gm}{v^2}$$

$$v^3 = \frac{2\pi Gm}{T}$$

$$= \frac{2\pi\left(6.67 \times 10^{-11}\ \frac{\text{kg} \cdot \frac{\text{m}}{\text{s}^2} \cdot \text{m}^2}{\text{kg}^2}\right)\left(5.98 \times 10^{24}\ \text{kg}\right)}{86\ 400\ \text{s}}$$

$$= 3073\ \frac{\text{m}}{\text{s}} \times \frac{60\ \text{s}}{1\ \text{min}} \times \frac{60\ \text{min}}{1\ \text{h}} \times \frac{1\ \text{km}}{1000\ \text{m}}$$

$$v = 1.11 \times 10^4\ \text{km/h}$$

Statement: The orbital speed of a satellite in geosynchronous orbit is 1.11×10^4 km/h.

13. (a) Given: $m_{\text{Sun}} = 1.99 \times 10^{30}$ kg; $r_{\text{Mercury}} = 5.79 \times 10^{10}$ m; $r_{\text{Venus}} = 1.08 \times 10^{11}$ m; $r_{\text{Earth}} = 1.49 \times 10^{11}$ m; $r_{\text{Mars}} = 2.28 \times 10^{11}$ m; $G = 6.67 \times 10^{-11}$ N·m²/kg²

Required: v_{Mercury}; v_{Venus}; v_{Earth}; v_{Mars}

Analysis: $v = \sqrt{\frac{Gm}{r}}$

Solution: $v_{\text{Mercury}} = \sqrt{\dfrac{Gm_{\text{Sun}}}{r_{\text{Mercury}}}}$

$$= \sqrt{\dfrac{\left(6.67 \times 10^{-11} \ \dfrac{\cancel{\text{kg}} \cdot \dfrac{\cancel{\text{m}}}{\text{s}^2} \cdot \text{m}^2}{\cancel{\text{kg}^2}}\right)\left(1.99 \times 10^{30} \ \cancel{\text{kg}}\right)}{5.79 \times 10^{10} \ \cancel{\text{m}}}}$$

$v_{\text{Mercury}} = 4.79 \times 10^4 \text{ m/s}$

$v_{\text{Venus}} = \sqrt{\dfrac{Gm_{\text{Sun}}}{r_{\text{Venus}}}}$

$$= \sqrt{\dfrac{\left(6.67 \times 10^{-11} \ \dfrac{\cancel{\text{kg}} \cdot \dfrac{\cancel{\text{m}}}{\text{s}^2} \cdot \text{m}^2}{\cancel{\text{kg}^2}}\right)\left(1.99 \times 10^{30} \ \cancel{\text{kg}}\right)}{1.08 \times 10^{11} \ \cancel{\text{m}}}}$$

$v_{\text{Venus}} = 3.51 \times 10^4 \text{ m/s}$

$v_{\text{Earth}} = \sqrt{\dfrac{Gm_{\text{Sun}}}{r_{\text{Earth}}}}$

$$= \sqrt{\dfrac{\left(6.67 \times 10^{-11} \ \dfrac{\cancel{\text{kg}} \cdot \dfrac{\cancel{\text{m}}}{\text{s}^2} \cdot \text{m}^2}{\cancel{\text{kg}^2}}\right)\left(1.99 \times 10^{30} \ \cancel{\text{kg}}\right)}{1.49 \times 10^{11} \ \cancel{\text{m}}}}$$

$v_{\text{Earth}} = 2.98 \times 10^4 \text{ m/s}$

$v_{\text{Mars}} = \sqrt{\dfrac{Gm_{\text{Sun}}}{r_{\text{Mars}}}}$

$$= \sqrt{\dfrac{\left(6.67 \times 10^{-11} \ \dfrac{\cancel{\text{kg}} \cdot \dfrac{\cancel{\text{m}}}{\text{s}^2} \cdot \text{m}^2}{\cancel{\text{kg}^2}}\right)\left(1.99 \times 10^{30} \ \cancel{\text{kg}}\right)}{2.28 \times 10^{11} \ \cancel{\text{m}}}}$$

$v_{\text{Mars}} = 2.41 \times 10^4 \text{ m/s}$

Statement: The orbital speed of Mercury is 4.79×10^4 m/s.
The orbital speed of Venus is 3.51×10^4 m/s.
The orbital speed of Earth is 2.98×10^4 m/s.
The orbital speed of Mars is 2.41×10^4 m/s.

(b) The farther a planet is from the Sun, the slower its orbital speed.

14. Given: d = 410 km = 4.1×10^5 m; $r_{\text{Moon}} = 1.74 \times 10^6$ m; $m = 7.36 \times 10^{22}$ kg; $G = 6.67 \times 10^{-11}$ N·m²/kg²

Required: v; T

Analysis: $v = \sqrt{\dfrac{Gm}{r}}$; $T = \dfrac{2\pi r}{v}$. First, calculate the orbital radius:

$$\begin{aligned} r &= d + r_{\text{Moon}} \\ &= 4.1\times10^5 \text{ m} + 1.74\times10^6 \text{ m} \\ r &= 2.15\times10^6 \text{ m (one extra digit carried)} \end{aligned}$$

Solution:

$$\begin{aligned} v &= \sqrt{\frac{Gm}{r}} \\ &= \sqrt{\frac{\left(6.67\times10^{-11}\ \dfrac{\cancel{\text{kg}}\cdot\dfrac{\cancel{\text{m}}}{\text{s}^2}\cdot\text{m}^2}{\cancel{\text{kg}^2}}\right)\left(7.36\times10^{22}\ \cancel{\text{kg}}\right)}{2.15\times10^6\ \cancel{\text{m}}}} \\ &= 1.511\times10^3 \text{ m/s (two extra digit carried)} \\ v &= 1.5\times10^3 \text{ m/s} \end{aligned}$$

Determine the period:

$$\begin{aligned} T &= \frac{2\pi r}{v} \\ &= \frac{2\pi\left(2.15\times10^6\ \cancel{\text{m}}\right)}{1.511\times10^3\ \dfrac{\cancel{\text{m}}}{\text{s}}} \\ T &= 8.9\times10^3 \text{ s} \end{aligned}$$

Statement: The speed of the satellite is 1.5×10^3 m/s, and its period is 8.9×10^3 s.