## 7-2 Gravitational Acceleration

You can use the law of universal gravitation to find the gravitational acceleration, $g$, of any body if you know that body's mass and radius. For example, let's look at the situation on Earth. The weight of an object on Earth's surface is equal to the gravitational force between that object and Earth:

$$
m g=\frac{G m M}{d^{2}}
$$

The $m$ on the left represents the mass of an object, such as a human being. The $m$ on the right side of the equation stands for this same mass, so the term cancels out of the equation. The $M$ on the right represents the mass of Earth or other celestial body on which the person is standing. The $d$ in the denominator is equal to the radius of the celestial body. So the equation becomes

$$
g=\frac{G M}{d^{2}}
$$

In this equation, $g$ is the acceleration due to gravity on the celestial body in question. On Earth you already know that this value is $10.0 \mathrm{~m} / \mathrm{s}^{2}$.

## Solved Examples

Example 4: Temba is standing in the lunch line $6.38 \times 10^{6} \mathrm{~m}$ from the center of Earth. Earth's mass is $5.98 \times 10^{24} \mathrm{~kg}$. a) What is the acceleration due to gravity? b) When Temba eats his lunch and his mass increases, does this change the acceleration due to gravity?
a. Given: $\begin{array}{rlr}M & =5.98 \times 10^{24} \mathrm{~kg} \quad & \text { Unknown: } g=\text { ? } \\ d & =6.38 \times 10^{6} \mathrm{~m} & \text { Original equation: } g=\frac{G M}{d^{2}} \\ G & =6.67 \times 10^{-11} \mathrm{~N} \cdot \mathrm{~m}^{2} / \mathrm{kg}^{2} & \end{array}$

Solve: $g=\frac{G M}{d^{2}}=\frac{\left(6.67 \times 10^{-11} \mathrm{~N} \cdot \mathrm{~m}^{2} / \mathrm{kg}^{2}\right)\left(5.98 \times 10^{24} \mathrm{~kg}\right)}{\left(6.38 \times 10^{6} \mathrm{~m}\right)^{2}}=\mathbf{9 . 8 0} \mathbf{~ m} / \mathrm{s}^{\mathbf{2}}$
b. No, his acceleration due to gravity does not change because it is not dependent on his mass.

Example 5: The sun has a mass that is 333000 times Earth's mass and a radius 109 times Earth's radius. What is the acceleration due to gravity on the sun?

Solution: One way to solve this exercise is to actually multiply the given values by the mass and radius of Earth. However, there is an easier and much
neater way to come up with the correct answer. By working with ratios, you can find an answer without any information about Earth.

$$
\text { Given: } \begin{aligned}
M_{\mathrm{S}} & =333000 \mathrm{M}_{\mathrm{E}} & & \text { Unknown: } g=\text { ? } \\
G & =6.67 \times 10^{-11} \mathrm{~N} \cdot \mathrm{~m}^{2} / \mathrm{kg}^{2} & & \text { Original equation: } g=\frac{G M}{d^{2}} \\
d_{\mathrm{S}} & =109 \mathrm{~d}_{\mathrm{E}} & &
\end{aligned}
$$

Solve: Set up the above equation as a ratio of sun to Earth before substituting numbers.

$$
\frac{g_{\mathrm{S}}}{g_{\mathrm{E}}}=\frac{\frac{G M_{\mathrm{S}}}{d_{\mathrm{S}}^{2}}}{\frac{G M_{\mathrm{E}}}{d_{\mathrm{E}}^{2}}}
$$

Simplifying gives $\quad \frac{g_{\mathrm{S}}}{g_{\mathrm{E}}}=\frac{M_{\mathrm{S}} d_{\mathrm{E}}^{2}}{M_{\mathrm{E}} d_{\mathrm{S}}{ }^{2}}=\frac{\left(333000 M_{\mathrm{E}}\right)\left(d_{\mathrm{E}}^{2}\right)}{\left(M_{\mathrm{E}}\right)\left(109 d_{\mathrm{E}}\right)^{2}}=\frac{(333000)}{(109)^{2}}=28.0$
Therefore, $g_{\mathrm{S}}=28.0 g_{\mathrm{E}}$ so the acceleration due to gravity on the sun is 28.0 times what it is on Earth. In other words, it is 28.0 times $10.0 \mathrm{~m} / \mathrm{s}^{2}$, or $280 . \mathrm{m} / \mathrm{s}^{2}$.

## Practice Exercises

Exercise 7: In The Little Prince, the Prince visits a small asteroid called B612. If asteroid B612 has a radius of only 20.0 m and a mass of $1.00 \times 10^{4} \mathrm{~kg}$, what is the acceleration due to gravity on asteroid B612?

Answer: $\qquad$
Exercise 8: In Exercise 5 in the previous section, what is the Andromeda Galaxy's acceleration rate toward the Milky Way?

Answer:

Exercise 9: Black holes are suspected when a visible star is being noticeably pulled by an invisible partner that is more than 3 times as massive as the sun. a) If a red giant (a dying star) is gravitationally accelerated at $0.075 \mathrm{~m} / \mathrm{s}^{2}$ toward an object that is $9.4 \times 10^{10} \mathrm{~m}$ away, how large a mass must the unseen body possess? b) How many times more massive is the object than the sun? $\left(M_{\mathrm{s}}=1.99 \times 10^{30} \mathrm{~kg}\right)$

Answer: a. $\qquad$
Answer: b.
Exercise 10: The planet Saturn has a mass that is 95 times Earth's mass and a radius that is 9.4 times Earth's radius. What is the acceleration due to gravity on Saturn?

$\qquad$

# 7. $1.67 \times 10^{-9} \mathrm{~m} / \mathrm{s}^{2}$ 9. a) $9.9 \times 10^{30} \mathrm{~kg}$ <br> b) 5.0 times 

