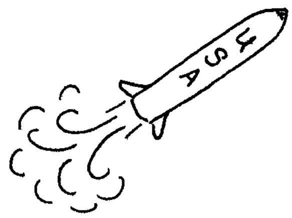
7-3 Escape Speed

Vocabulary **Escape Speed:** The minimum speed an object must possess in order to escape from the gravitational pull of a body.

In Chapter 5, you worked with gravitational potential energy and kinetic energy. When an object moves away from Earth, its gravitational potential energy increases. Since its total energy is conserved, its kinetic energy decreases. When the object is close to Earth, the gravitational force on it is a fairly constant *mg*. However, as you know, the gravitational force drops rapidly as you get farther from Earth. If an object moves upward from Earth with enough speed, it will never run out of kinetic energy and will escape from Earth.

The escape speed for an object leaving the surface of any celestial body of mass M and radius d is

$$v = \sqrt{\frac{2GM}{d}}$$



Notice that the mass of the escaping object does not affect the escape speed.

Solved Examples

Example 6: Earth has a mass of 5.98×10^{24} kg and a radius of 6.38×10^{6} km. What is the escape speed of a rocket launched on Earth?

Given: $M = 5.98 \times 10^{24}$ kg
$d = 6.38 \times 10^{6}$ m
$G = 6.67 \times 10^{-11}\ \mathrm{N \cdot m^2/kg^2}$

Unknown: $v = ?$
Original equation: $v = \sqrt{\frac{2GM}{d}}$

Solve: $v = \sqrt{\frac{2GM}{d}} = \sqrt{\frac{2(6.67 \times 10^{-11}\ \mathrm{N \cdot m^2/kg^2})(5.98 \times 10^{24}\ \mathrm{kg})}{6.38 \times 10^{6}\ \mathrm{m}}}$

$= \mathbf{11\ 200\ m/s}$

Any rocket trying to escape Earth's gravitational pull must be going at least 11 200 m/s before engine cut-off, in order to get away.

Example 7: Compare Example 6 with the escape speed of a rocket launched from the moon. The mass of the moon is 7.35×10^{22} kg and the radius is 1.74×10^{6} m.

Given: $M = 7.35 \times 10^{22}$ kg
$d = 1.74 \times 10^{6}$ m
$G = 6.67 \times 10^{-11}\ \mathrm{N \cdot m^2/kg^2}$

Unknown: $v = ?$
Original equation: $v = \sqrt{\frac{2GM}{d}}$

$$\textit{Solve:}\ v = \sqrt{\frac{2GM}{d}} = \sqrt{\frac{2(6.67 \times 10^{-11}\ \text{N}\cdot\text{m}^2/\text{kg}^2)(7.35 \times 10^{22}\ \text{kg})}{1.74 \times 10^{6}\ \text{m}}} = \mathbf{2370\ m/s}$$

Notice that you can escape from the moon by traveling much more slowly than you must travel to escape the gravitational pull of Earth. This is why launching a Lunar Module from the moon's surface was so much easier than launching an *Apollo* spacecraft from Earth.

Practice Exercise

Exercise 11: How fast would you need to travel a) to escape the gravitational pull of the sun? ($M_S = 1.99 \times 10^{30}$ kg, $d_S = 6.96 \times 10^{8}$ m) b) As the sun begins to die, it will become a red giant. This means that its mass will remain the same but its diameter will increase substantially (perhaps even out as far as Earth's orbit!). When the sun becomes a red giant, will its escape speed be greater than, less than, or the same as, it is now?

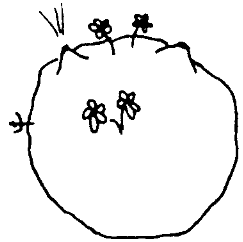
Answer: **a.** ____________________

Answer: **b.** ____________________

Exercise 12: How fast would the moon need to travel in order to escape the gravitational pull of Earth, if Earth has a mass of 5.98×10^{24} kg and the distance from Earth to the moon is 3.84×10^{8} m?

Answer: ____________________

Exercise 13: What is the escape speed needed a) to escape the gravitational pull of Asteroid B612 (see Exercise 7)? b) What would happen if you jumped up on Asteroid B612?



Answer: **a.** ______________________

Answer: **b.** ________________________________

Exercise 14: Scotty finds it difficult to play catch on planet Apgar because the planet's escape speed is only 5.00 m/s, and if Scotty throws the ball too hard, it flies away. If planet Apgar has a mass of 1.56×10^{15} kg, what is its radius?

Answer: ______________________

11. a) 618 000 m/s
13. a) 2.58×10^{-4} m/s