

ESCAPE VELOCITY EXAMPLES

1. Escape velocity is the speed that an object needs to be traveling to break free of planet or moon's gravity and enter orbit. For example, a spacecraft leaving the surface of Earth needs to be going 7 miles per second, or nearly 25,000 miles per hour, to enter orbit.



A Delta II rocket blasting off. A large amount of energy is needed to achieve escape velocity. *Photo from Jet Propulsion Laboratory's Planetary Missions & Instruments image gallery <http://www-b.jpl.nasa.gov/pictures/browse/pmi.html>*

2. The ability to use and compute square roots is often a necessary tool in physics. For example, square roots are used to compute the “**minimum**” velocity a spacecraft must have to escape the gravitational force of a planet. The “escape” velocity, “**v**”, can be calculated using the following formula:

Escape Velocity

$$V = \sqrt{\frac{2GM}{r}}$$

In this formula, “G” is a gravitational constant, “M” is the mass of the planet, and “r” is the radius of the planet.

3. Since escape velocity depends on the mass of the planet or moon from which a spacecraft is blasting, a spacecraft leaving the moon's surface could go slower than one blasting off from the Earth, because the moon has less gravity than the Earth. On the other hand, the escape velocity for Jupiter would be many times that of Earth's because Jupiter is so huge and has so much gravity.

4. **Example:** Compute the “**escape**” velocity for Earth if its mass is 5.98×10^{24} kg, its radius is 6.37×10^6 m, and $G = 6.67 \times 10^{-11}$ N·m²/Kg². The abbreviation “**N**” represents Newton, a unit of force in the metric system. Using these constraints, the answers will be in m/s.

$$1 \text{ N} = \frac{1 \text{ kg} \cdot \text{m}}{\text{s}^2}$$

$$V = \sqrt{\frac{2GM}{r}}$$

$$\sqrt{\frac{2(6.67 \times 10^{-11})(5.98 \times 10^{24})}{6.37 \times 10^6}}$$

$$\sqrt{1.2523265 \times 10^8}$$

$$\approx 1.12 \times 10^4$$

The escape velocity for Earth is approximately 1.12×10^4 m/s.

5. Point out that the gravitational constant is given in **N·m²/kg²**. The abbreviation “**N**” stands for “**Newton**.” One “**Newton**” of force acting on a mass of one kilogram causes acceleration of one meter per second per second (the thought process in this application is challenging. Exceptional students will have no problem but it may be easier for “**average**” students to accept this unit instead of “**deriving**” it).

6. You may want to show students why the answer is labeled in m/s.

$$G \text{ is in } \frac{Nm^2}{(kg)^2} \text{ with } N \text{ in } \frac{kg(m)}{s^2}.$$

$$\text{Thus } G \text{ is in } \frac{m^3}{kg(s^2)}.$$

M is in kg.
R is in m.

$$\text{Therefore, } \frac{2GM}{r} \text{ is in } \frac{\frac{m^3}{kg(s^2)} \bullet kg}{m} \text{ or } \frac{m^2}{s^2} \text{ or } \frac{m}{s}.$$

$$\text{And } \sqrt{\frac{2GM}{r}} \rightarrow \sqrt{\frac{m^2}{s^2}} \text{ or } \frac{m}{s}.$$

7. **Thought Provoker:** Is it better to launch a ship into orbit from near or away from the equator? (AWAY. The radius is greater at the equator than at the poles. This lowers the escape velocity.)
8. **Thought Provoker:** Why is “mass” important? (Mass is important because of two major factors affecting how things move in space: inertia and gravity. The more mass something has, the more inertia and gravity affect it. That is why heavy things (things with a lot of mass) are hard to move. When an object is sitting still, it resists moving, and the more mass it has, the more it resists. The amount of thrust needed to move something and how fast it ends up moving are both directly tied to its mass. On the other hand, once something massive starts moving, it is very hard to stop. This is also due to the relationship between mass and inertia. Gravity is also proportional to how much mass each thing has. The bigger an object is, the larger the gravitational pull it exerts. Because of gravity and inertia, the more massive something is, the harder it is to get into space, the harder it is to keep it there, and the harder it is to move it where you want it to go when it is there.)
9. **Thought Provoker:** Why is it difficult to plan intra-planet missions? (One reason that manned missions to other planets are difficult to plan is that a ship would have to take enough fuel into space to blast off of the other planet when the astronauts wanted to go home. The weight of the fuel would make the spaceship so heavy it would be hard to blast it off Earth.)

Name: _____

Date: _____

Class: _____

ESCAPE VELOCITY WORKSHEET

Compute the escape velocity for the indicated planet using the formula below.

Use $G = 6.67 \times 10^{-11} \frac{N \cdot m^2}{kg^2}$

$$V = \sqrt{\frac{2GM}{r}}$$



1. Mars: mass 6.46×10^{23} kg; radius 3.39×10^6 m

2. Mercury: mass 3.35×10^{23} kg; radius 2.44×10^6 m

3. Venus: mass 4.90×10^{24} kg; radius 6.06×10^6 m



ESCAPE VELOCITY WORKSHEET KEY

Compute the escape velocity for the indicated planet using the formula below. Use $G =$

$$6.67 \times 10^{-11} \frac{N \cdot m^2}{kg^2}.$$

$$\mathbf{V} = \sqrt{\frac{2GM}{r}}$$

1. Mars: mass 6.46×10^{23} kg; radius 3.39×10^6 m

$$\begin{aligned} \mathbf{V} &= \sqrt{\frac{2GM}{r}} \\ &= \sqrt{\frac{2(6.67 \times 10^{-11})(6.46 \times 10^{23})}{3.39 \times 10^6}} \\ &= \sqrt{25420766} \\ &\approx 5.04 \times 10^3 \end{aligned}$$

The escape velocity for Earth is approximately 5.04×10^3 m/s.

2. Mercury: mass 3.35×10^{23} kg; radius 2.44×10^6 m

$$\begin{aligned} \mathbf{V} &= \sqrt{\frac{2GM}{r}} \\ &= \sqrt{\frac{2(6.67 \times 10^{-11})(3.35 \times 10^{23})}{2.44 \times 10^6}} \\ &= \sqrt{18315163.93} \\ &\approx 4.28 \times 10^3 \end{aligned}$$

The escape velocity for Earth is approximately 4.28×10^3 m/s.

3. Venus: mass 4.90×10^{24} kg; radius 6.06×10^6 m

$$\begin{aligned} \mathbf{V} &= \sqrt{\frac{2GM}{r}} \\ &= \sqrt{\frac{2(6.67 \times 10^{-11})(4.90 \times 10^{24})}{6.06 \times 10^6}} \\ &= \sqrt{107864686.5} \\ &\approx 1.04 \times 10^4 \end{aligned}$$

The escape velocity for Earth is approximately 1.04×10^4 m/s.

Student Name: _____

Date: _____

ESCAPE VELOCITY CHECKLIST

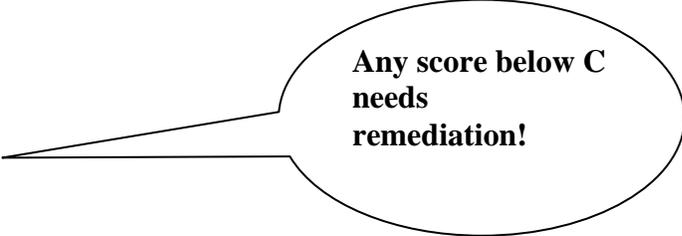
1. On question 1, did the student compute the escape velocity for the indicated planet?
 - a. Yes (25 points)
 - b. No, but only made minor mathematical errors (20 points)
 - c. No, used escape velocity formula incorrectly (15 points)
 - d. No, student could only set problem up but could not solve (10 points)

2. On question 2, did the student compute the escape velocity for the indicated planet?
 - a. Yes (25 points)
 - b. No, but only made minor mathematical errors (20 points)
 - c. No, used escape velocity formula incorrectly (15 points)
 - d. No, student could only set problem up but could not solve (10 points)

3. On question 3, did the student compute the escape velocity for the indicated planet?
 - a. Yes (25 points)
 - b. No, but only made minor mathematical errors (20 points)
 - c. No, used escape velocity formula incorrectly (15 points)
 - d. No, student could only set problem up but could not solve (10 points)

Total Number of Points _____

- A 67 points and above
- B 60 points and above
- C 52 points and above
- D 45 points and above
- F 44 points and below



**Any score below C
needs
remediation!**