FUNDAMENTALS OF PHYSICS

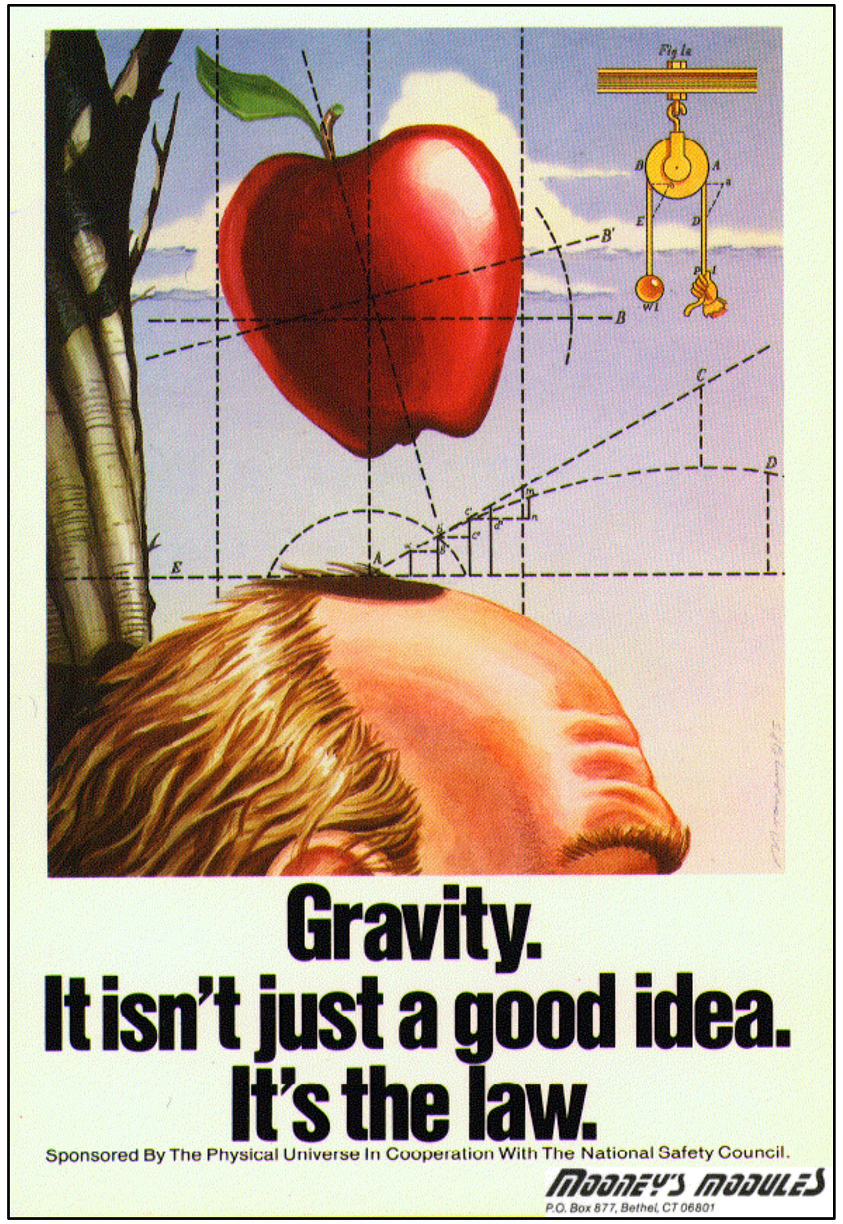
GRAVITY, PROJECTILES, AND SATELLITES

What is the force that keeps everything in place on the surface of the Earth?

What causes that force?

What causes that force?

THE LEGEND OF THE FALLING APPLE



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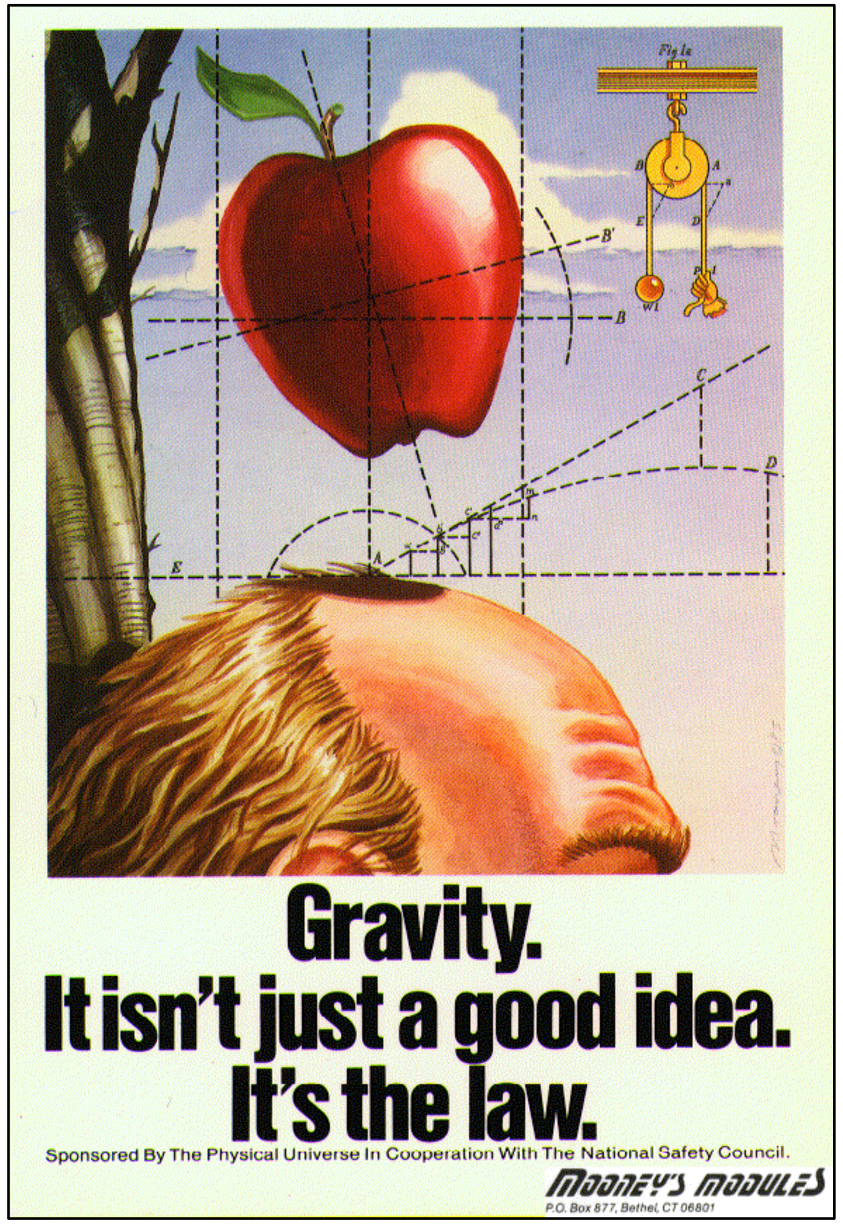

Isaac Newton, sitting under an apple tree, realized that the force between the apple and the Earth is the same as that between the planets and moons and everything else.

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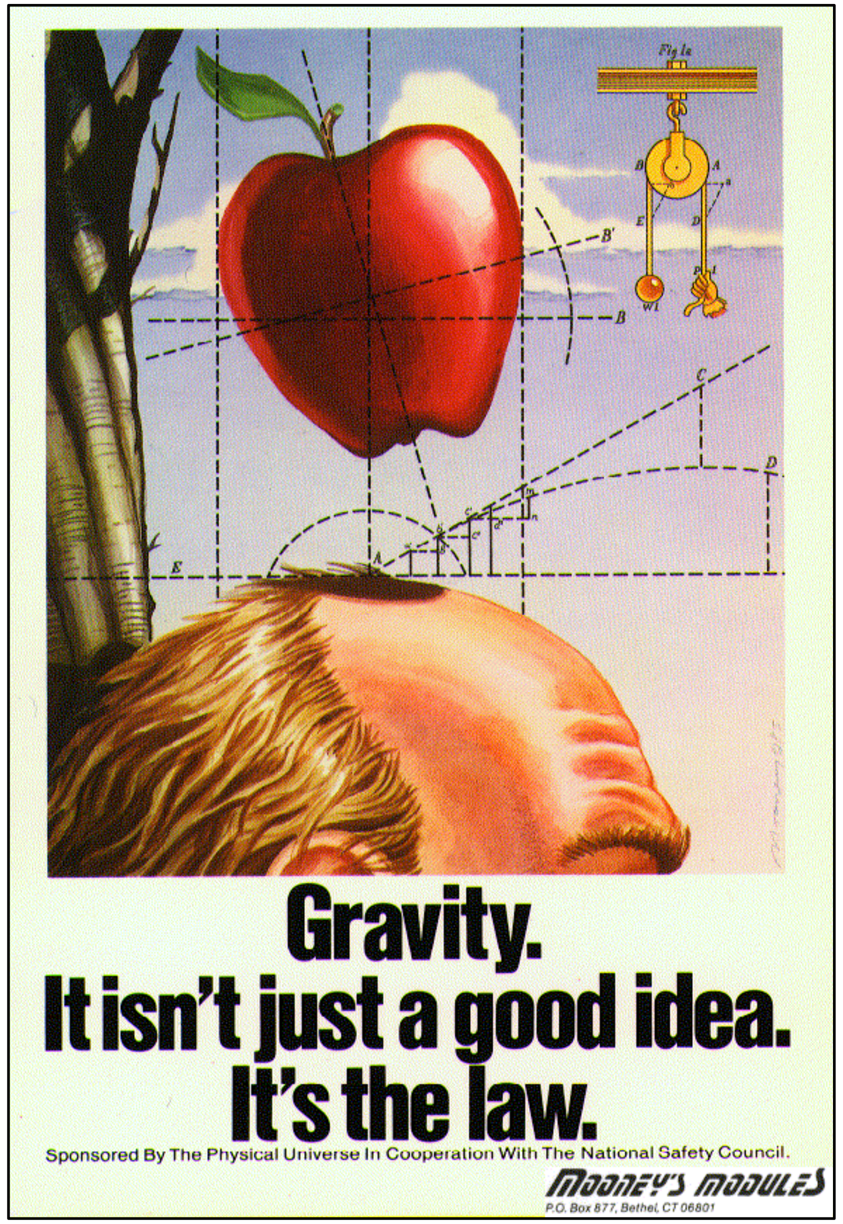

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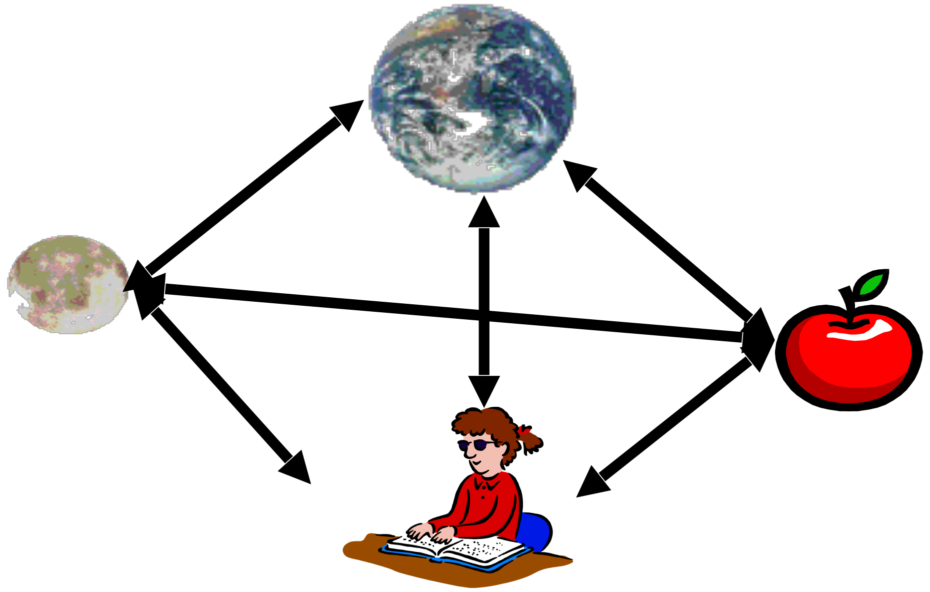
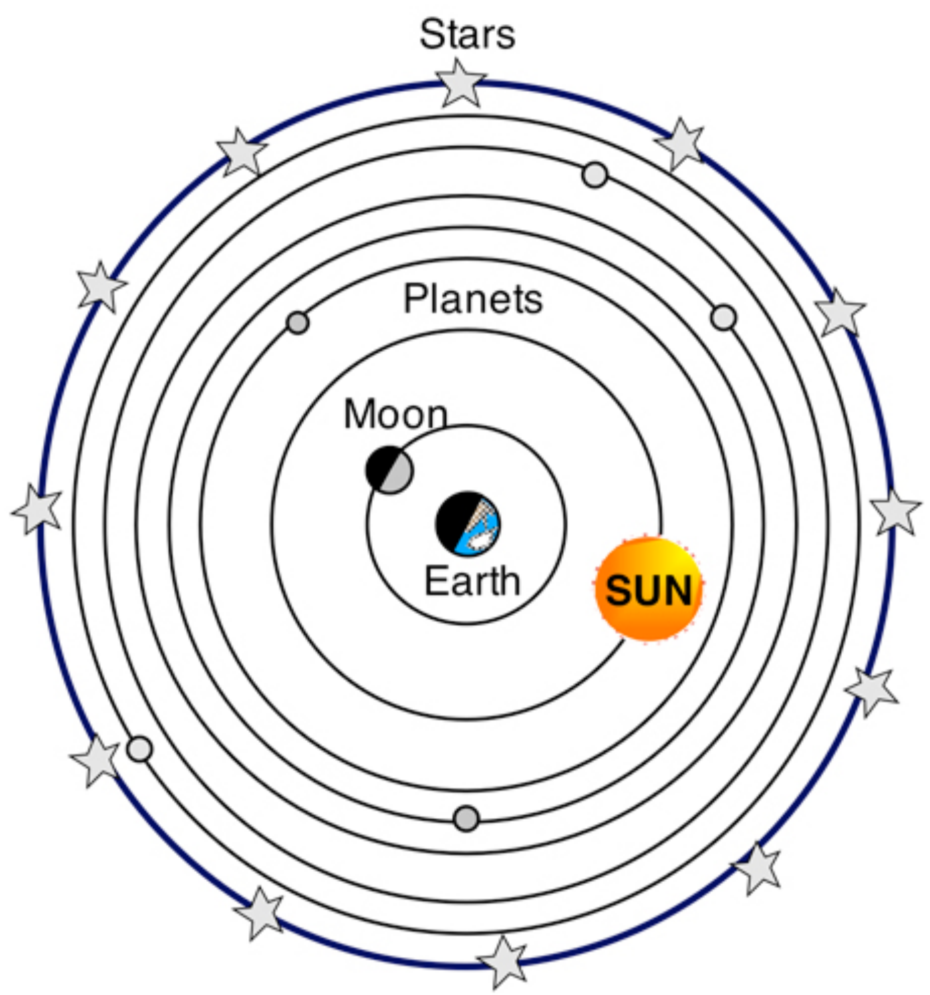
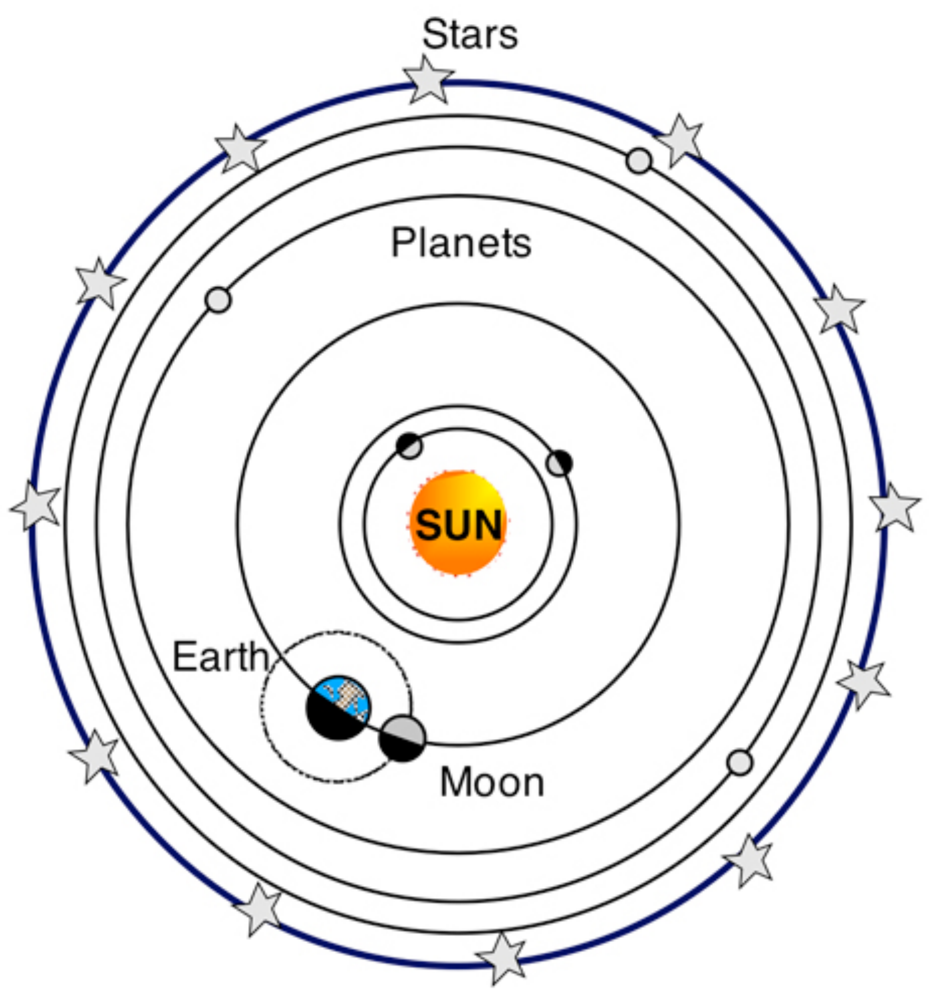
Isaac Newton did not discover gravity. He discovered that gravity is UNIVERSAL.







Geocentric Theory



Heliocentric Theory

THE UNIVERSAL LAW OF GRAVITY

Every body in the universe attracts every other body with a mutually attracting force.

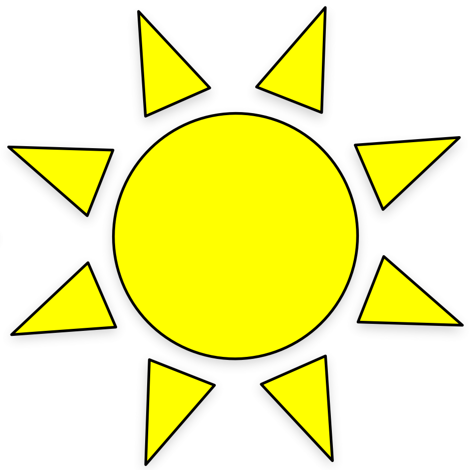
$$F_G = G\frac{m_1 * m_2}{d^2}$$

F_G= Gravitational Force : G = Gravitational Constant (6.67×10^{-11})

m_1 = mass of first object : m_2 = mass of second object

d = distance between the two objects

$\longleftarrow$ d $\longrightarrow$



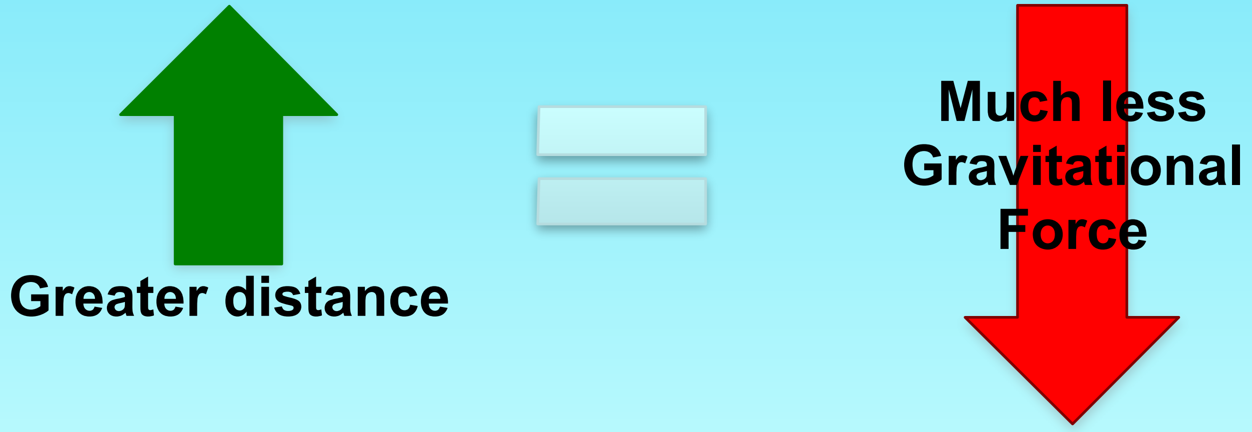
m_1 m_2

NEWTON'S LAW OF UNIVERSAL GRAVITY

$$F_G = G\frac{m_1 * m_2}{d^2}$$

Gravitational Force is directly proportional to both masses

and inversely AND exponentially proportional to distance.



SCIENTIFIC NOTATION

Scientific notation is often used as a more practical way to write numerical values that are **really large** or **really small**.

Really Large

Example: The mass of the Earth is 6,000,000,000,000,000,0000,000,000 kg.

We can (more practically) write this as 6×10^{24} kg.

*A positive exponent means to move the decimal point to the RIGHT.

Really Small

Example: The mass of an electron is .00000000000000000000000000000091 kg.

We can (more practically) write this as 9.1×10^{-31} kg.

*A negative exponent means to move the decimal point to the LEFT.

CONVERSION WITH SCIENTIFIC NOTATION

Example #1: 8.32×10^5

8 . 3 2 0 0 0 0 0 0 0 0 0

Example #2: 4.15×10^{-4}

0 0 0 0 4 . 1 5

CONVERSION WITH SCIENTIFIC NOTATION

Example #1: 8.32×10^5

+5 in the exponent means to move the decimal point 5 places to the right.

8 . 3 2 0 0 0 0 0 0 0 0 0

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0.0 0 0 4 1 5

4.15×10^{-4} = 0.000415

ENTERING SCIENTIFIC NOTATION

Ex: 3×10^{2}

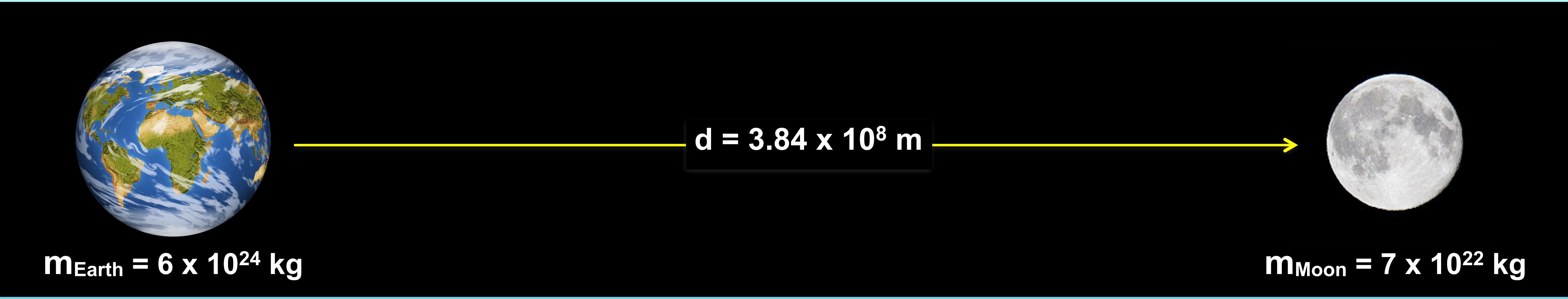
Process: | 3 | EXP | 2 | = |
|---|---|---|---|

Some calculators have the EE key instead of EXP, but it achieves the same result. EXP multiplies a number to a power of 10 entered after pressing the EXP key.

Ex: 7.4×10^{-5}

Process: | 7.4 | EXP | 5 | +/- | = |
|---|---|---|---|---|

Calculating the Gravitational Force between the Earth and the Moon:



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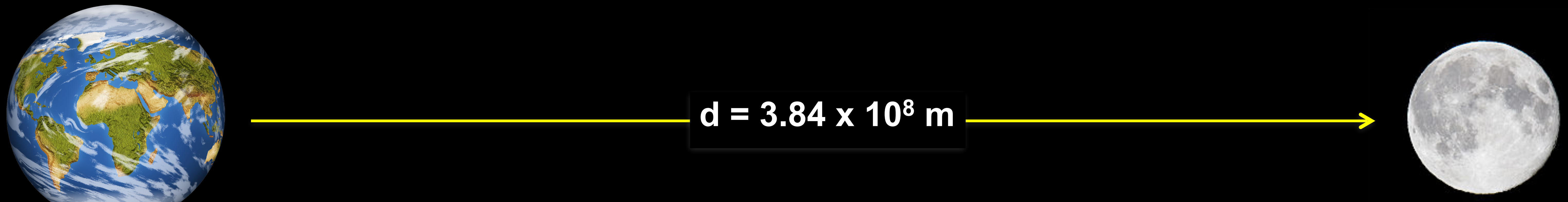

$m_{Earth} = 6 \times 10^{24}$ kg

$m_{Moon} = 7 \times 10^{22}$ kg

$$F_G = G\frac{m_1 m_2}{d^2}$$

Calculating the Gravitational Force between the Earth and the Moon:

$d = 3.84 \times 10^8$ m

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"G" is a physical constant (the gravitational constant) that will always be 6.67×10^{-11}.

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$$d = 10\ \text{m}$$

$m_{BusinessWoman} = 50\ \text{kg}$

$m_{Chef} = 50\ \text{kg}$

d = 10 m

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$$F_G = (6.67 \times 10^{-11})\frac{(50)(50)}{10^2}$$

$$F_G = (6.67 \times 10^{-11})\frac{2500}{100}$$

$$d = 10\ \text{m}$$

$m_{BusinessWoman}$ **= 50 kg**

m_{Chef} **= 50 kg**

$$F_G = G\frac{m_1 m_2}{d^2}$$

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*Note: Gravitational attraction between VERY LARGE BODIES is noticeable… between small objects it is not.

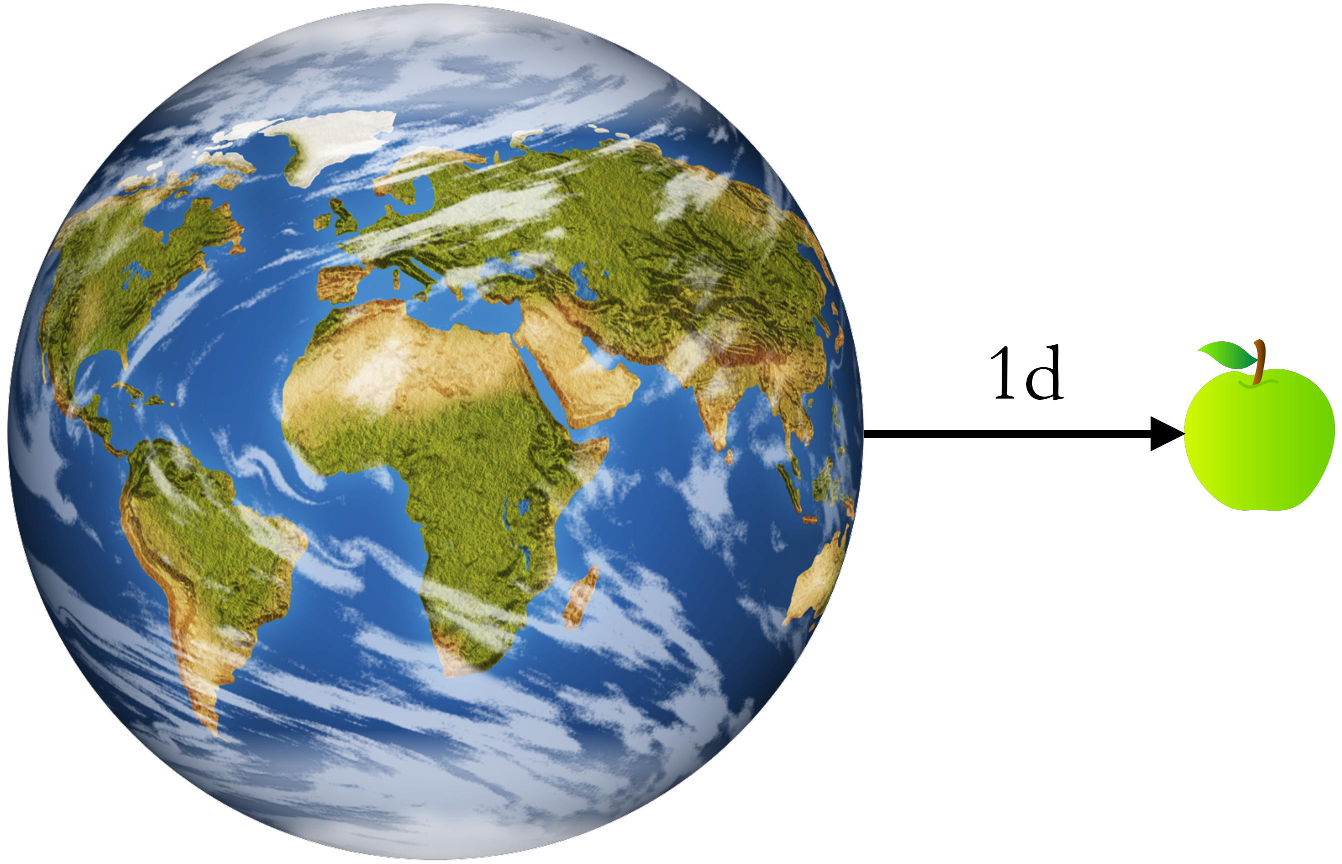
THE INVERSE-SQUARE LAW: GRAVITY AND DISTANCE

$$\textit{Intensity} \propto \frac{1}{\textit{distance}^2}$$

The greater the distance from Earth, the less the gravitational force on an object (*exponentially less*) .

No matter how great the distance, gravity approaches, but never reaches, zero.

INVERSE-SQUARE LAW



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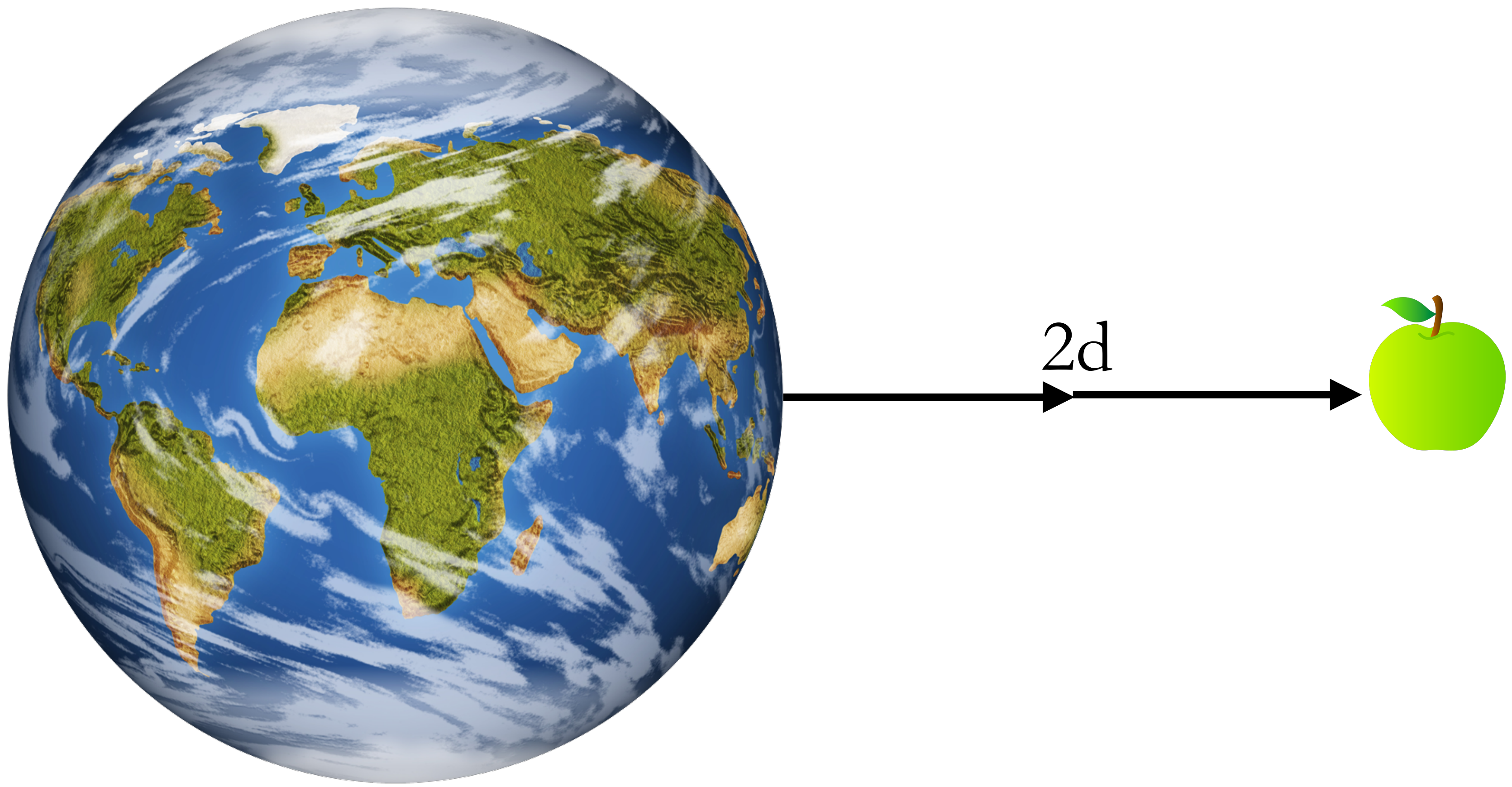

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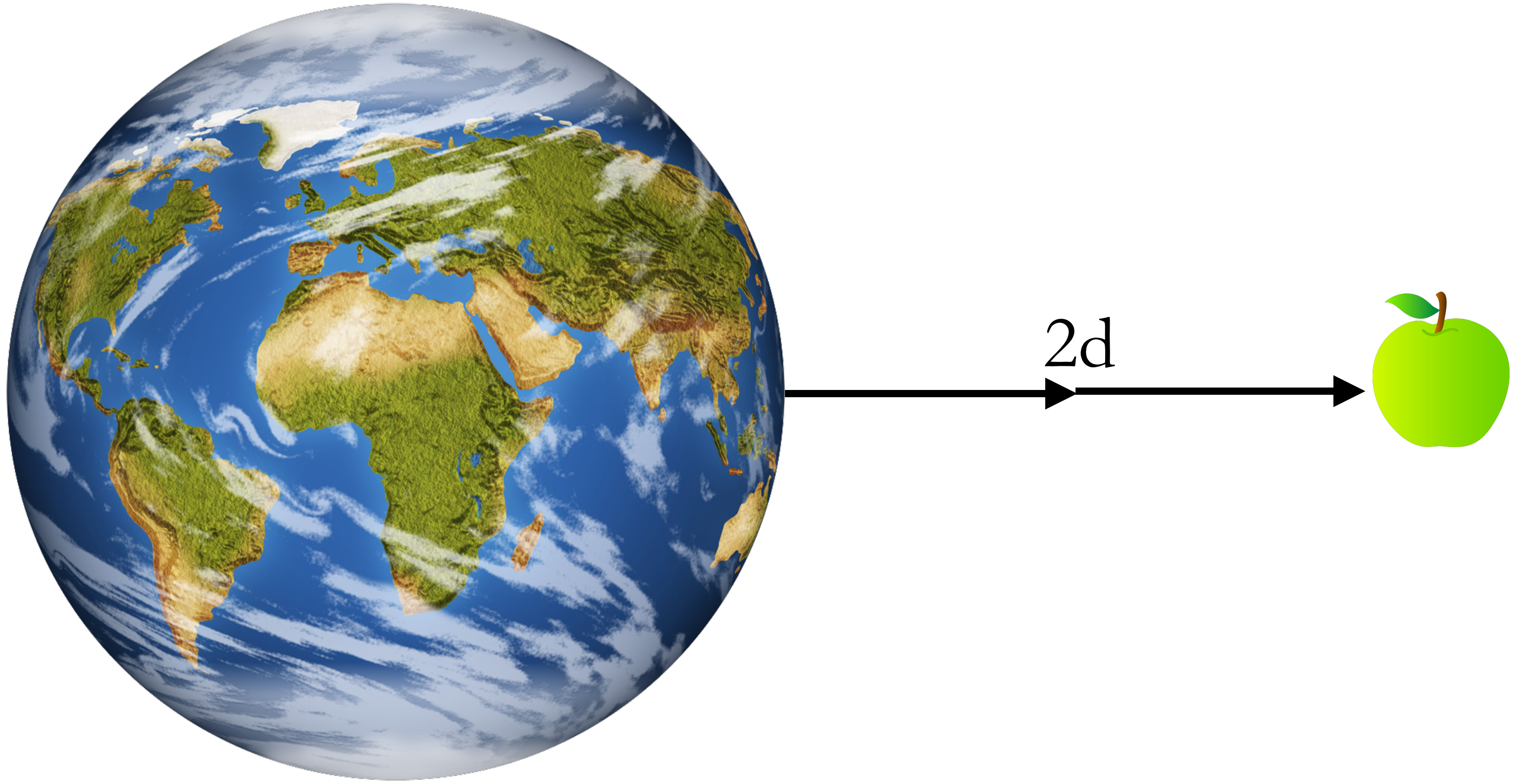
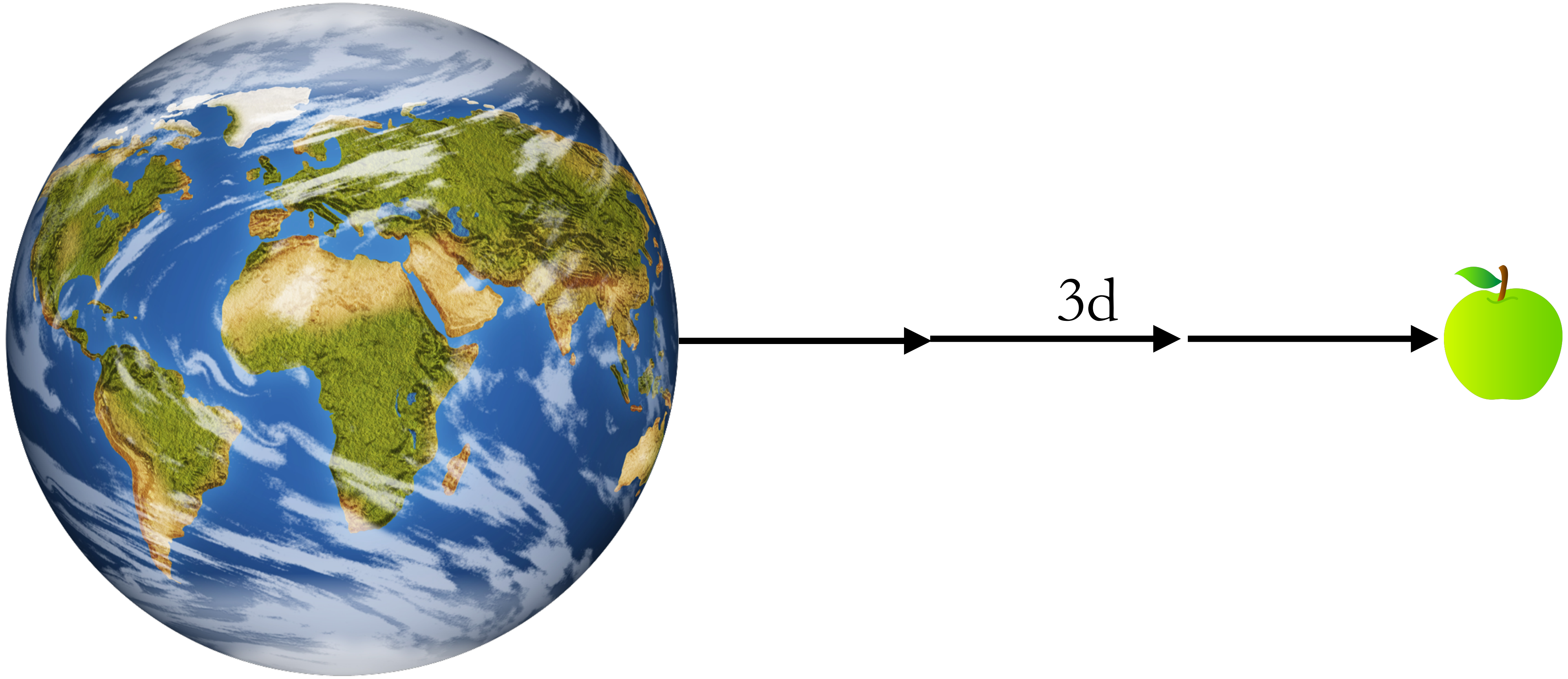


Distance increases by 2
Force decreases by $2^2 = 4$

INVERSE-SQUARE LAW



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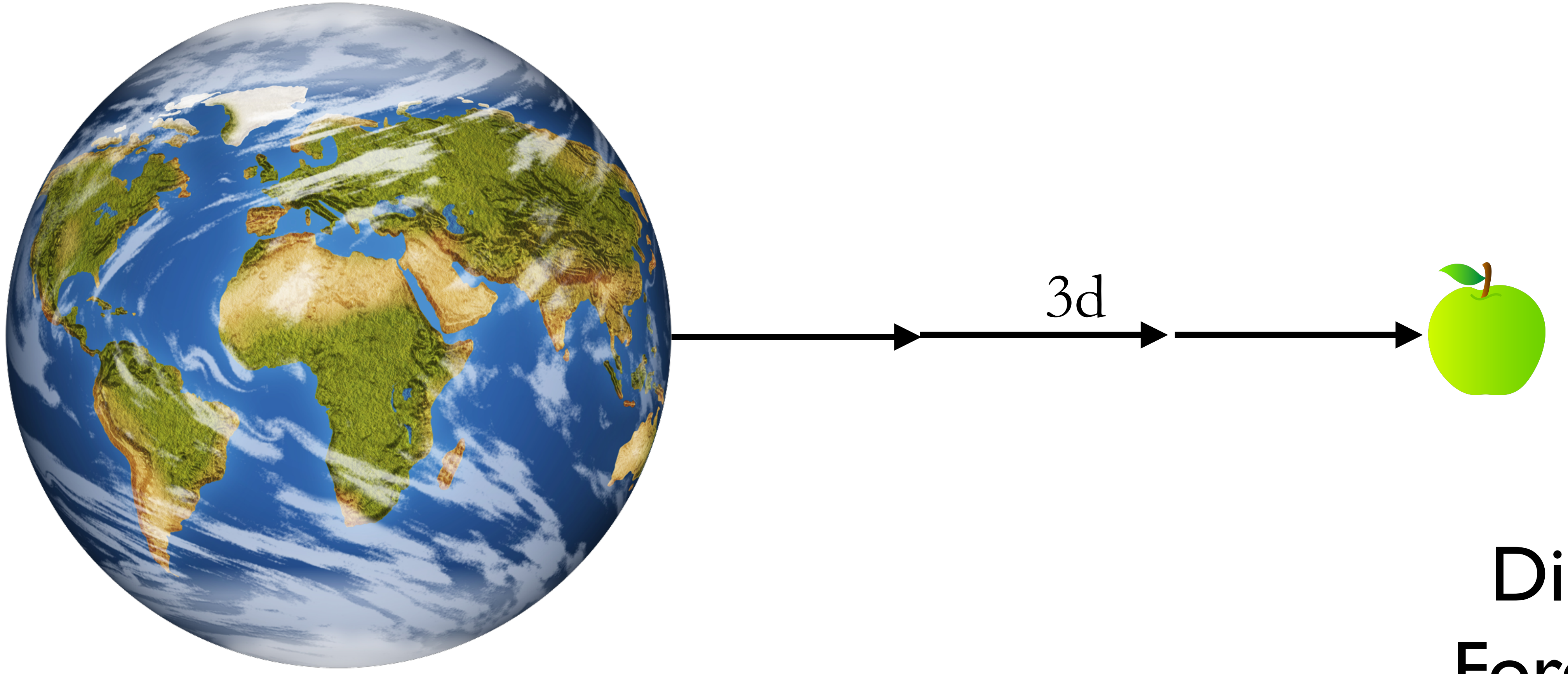
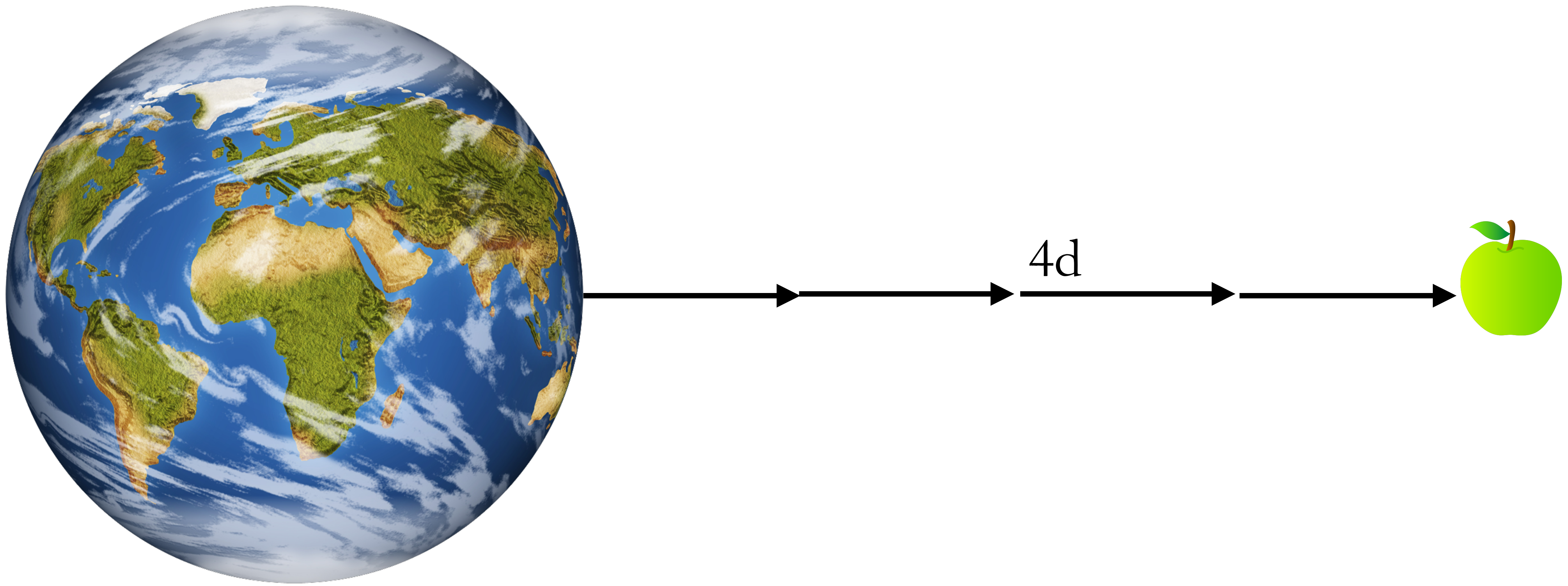


Distance increases by 3
Force decreases by $3^2 = 9$

INVERSE-SQUARE LAW



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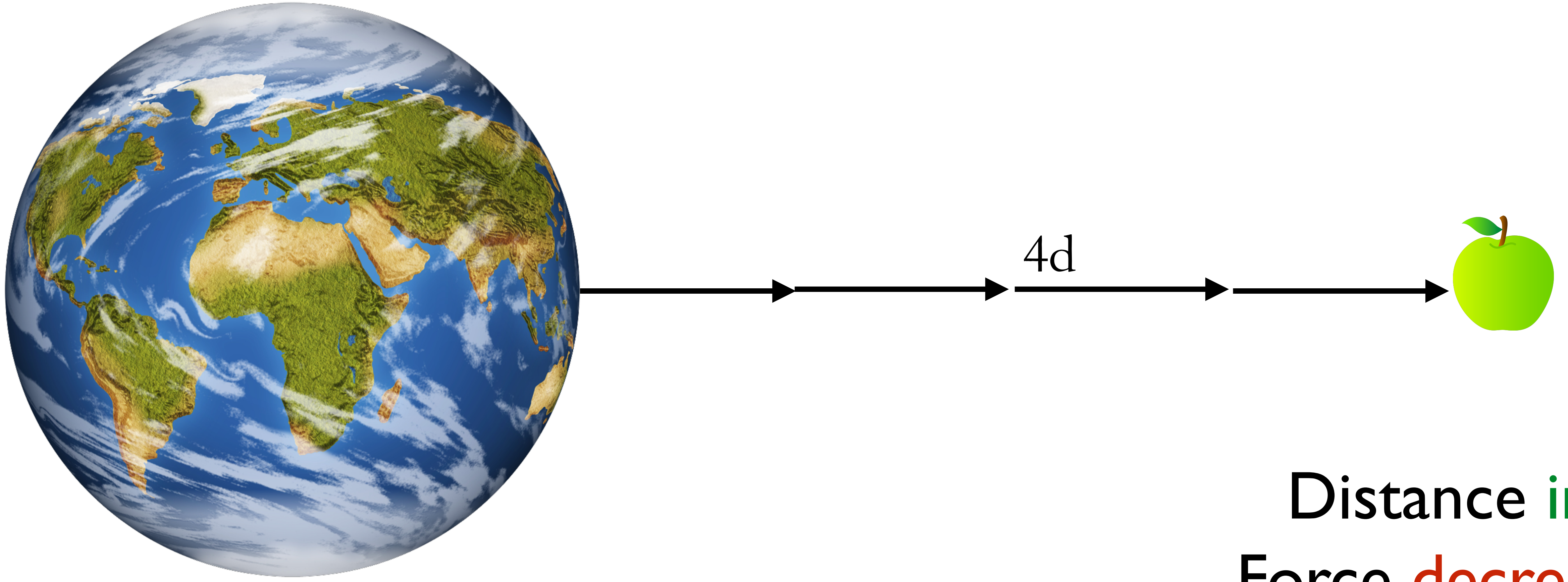
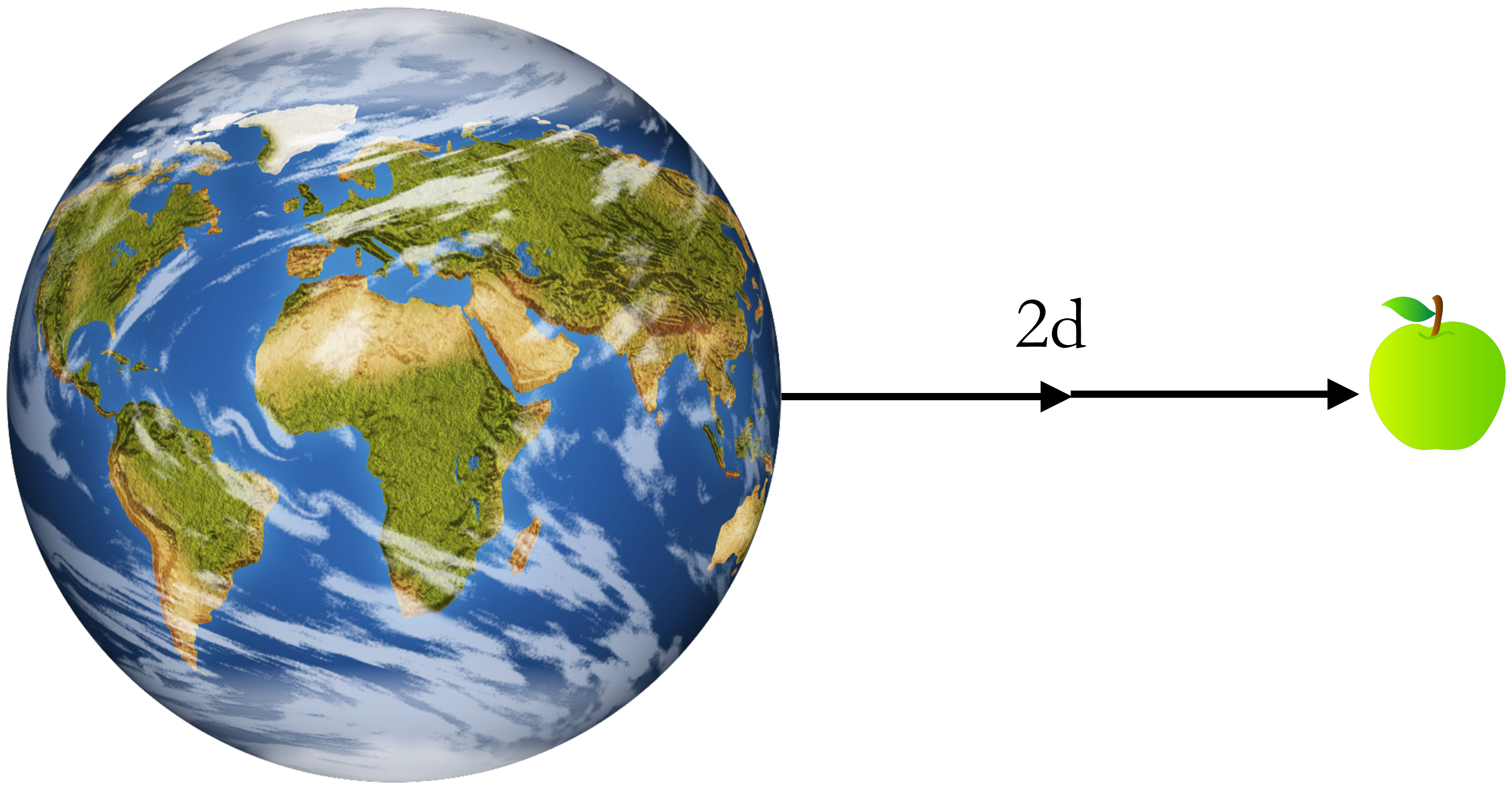


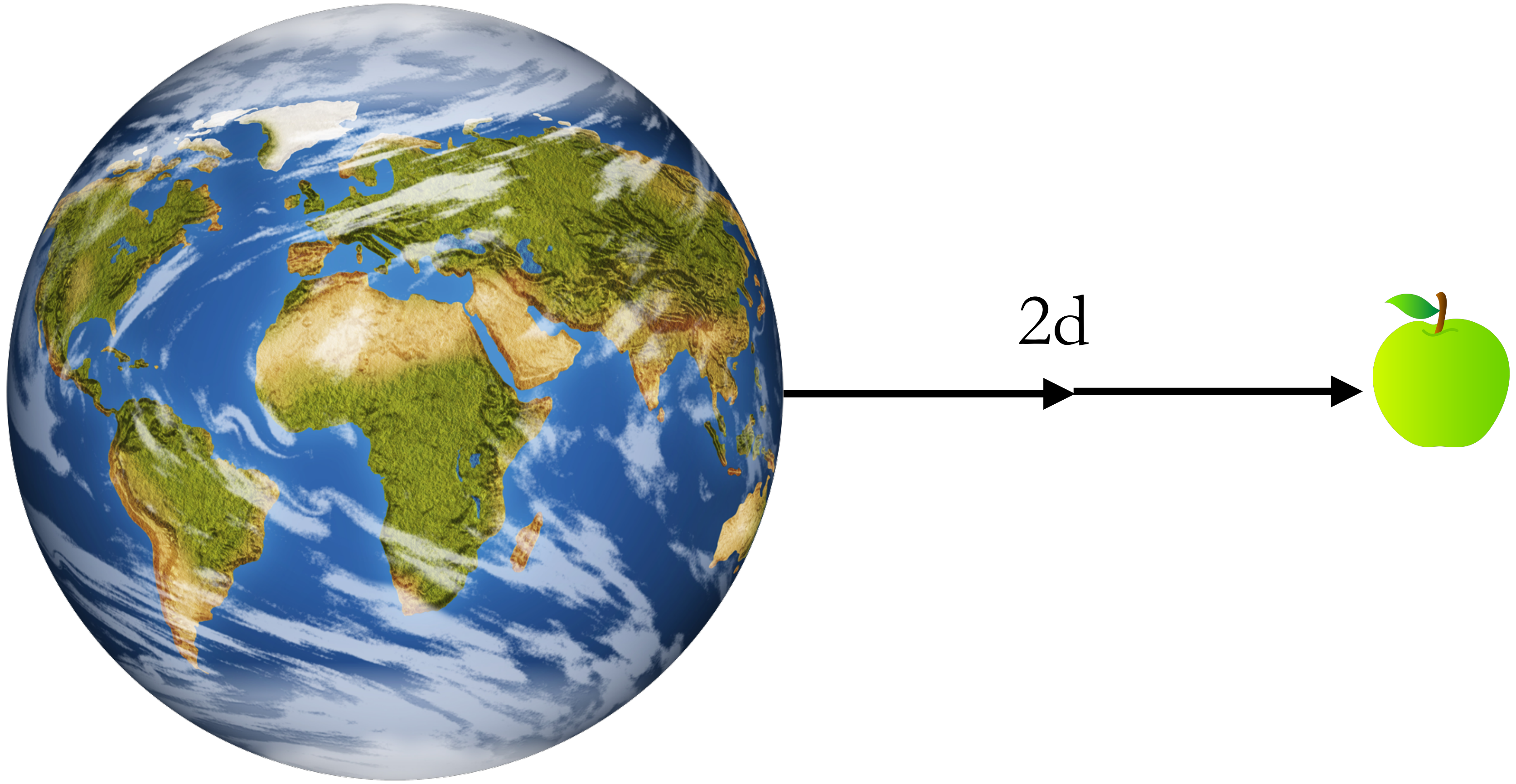
Distance increases by 4

Force decreases by $4^2 = 16$

INVERSE-SQUARE LAW



INVERSE-SQUARE LAW



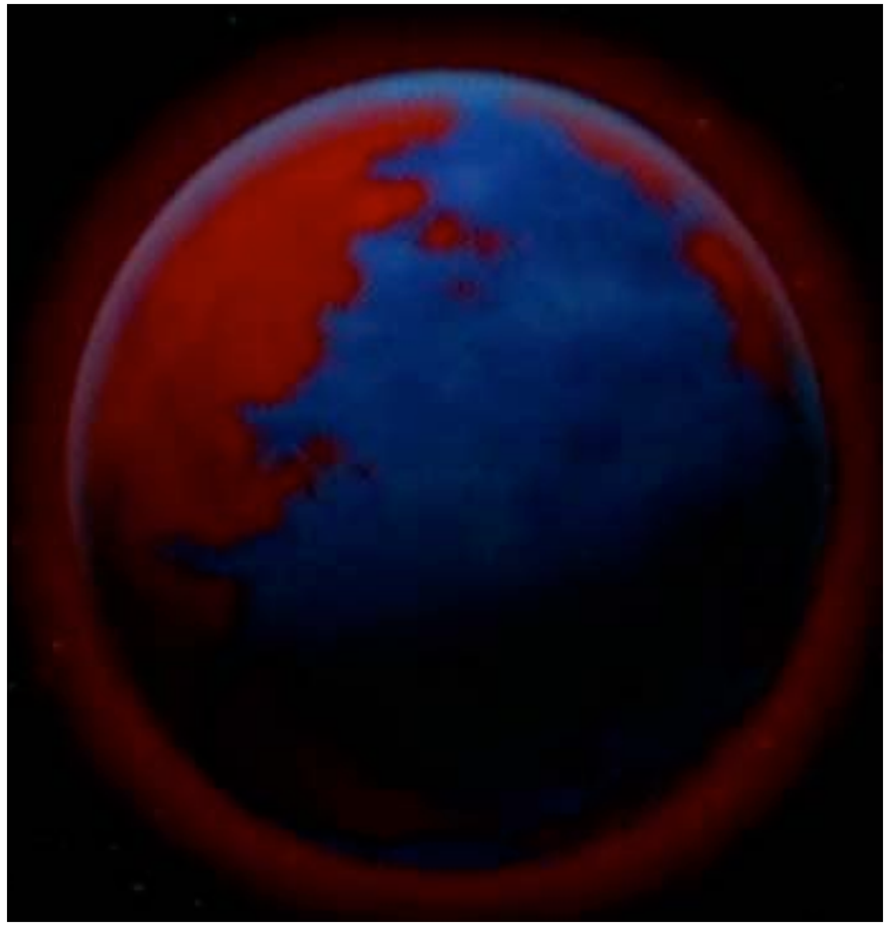
Distance decreases by 2

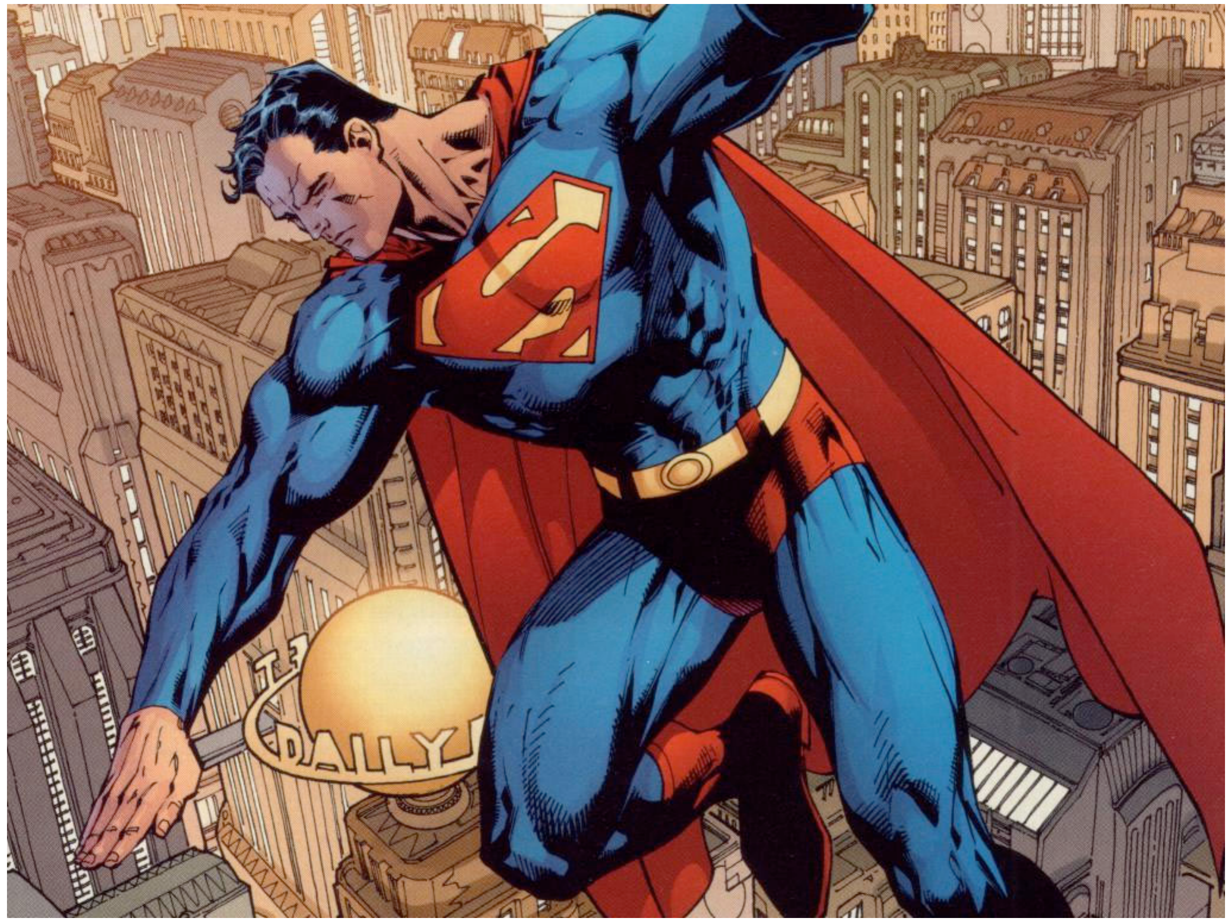
Force increases by $2^2 = 4$

WEIGHT AND WEIGHTLESSNESS

Weight:

The force exerted against a supporting floor or weighing scale due to gravity.





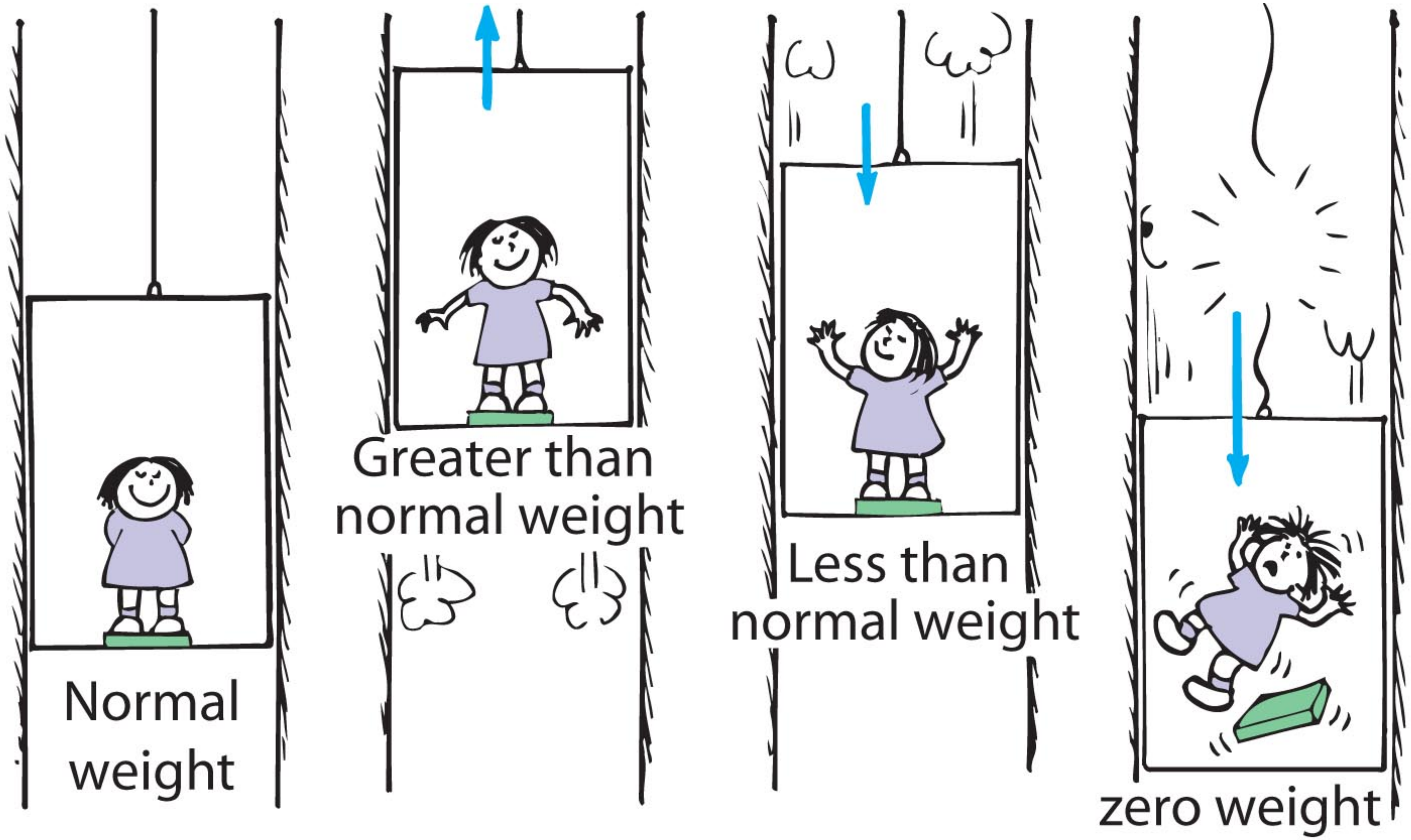
WEIGHT AND WEIGHTLESSNESS

Weightlessness:

A condition wherein a support force is lacking.

For example, free fall.

WEIGHT AND WEIGHTLESSNESS

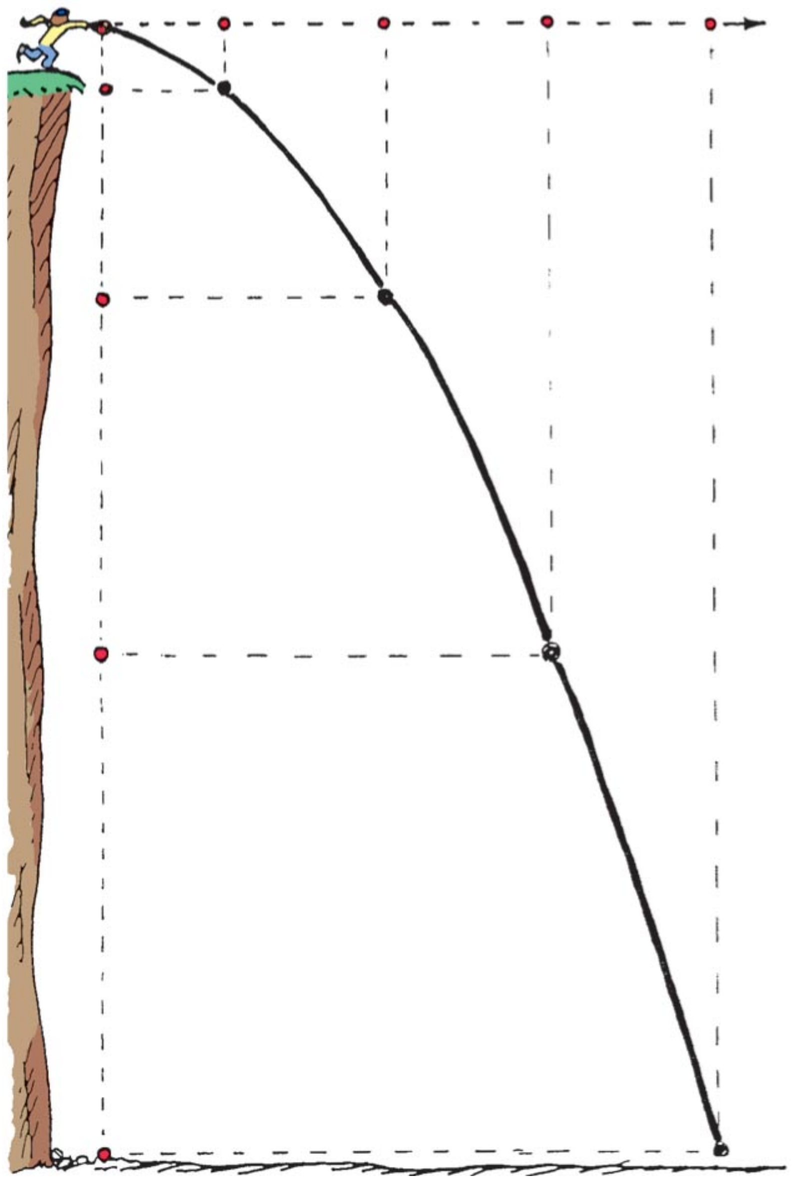


PROJECTILE MOTION

A **projectile** is any object that moves through the air or through space under the influence of gravity.

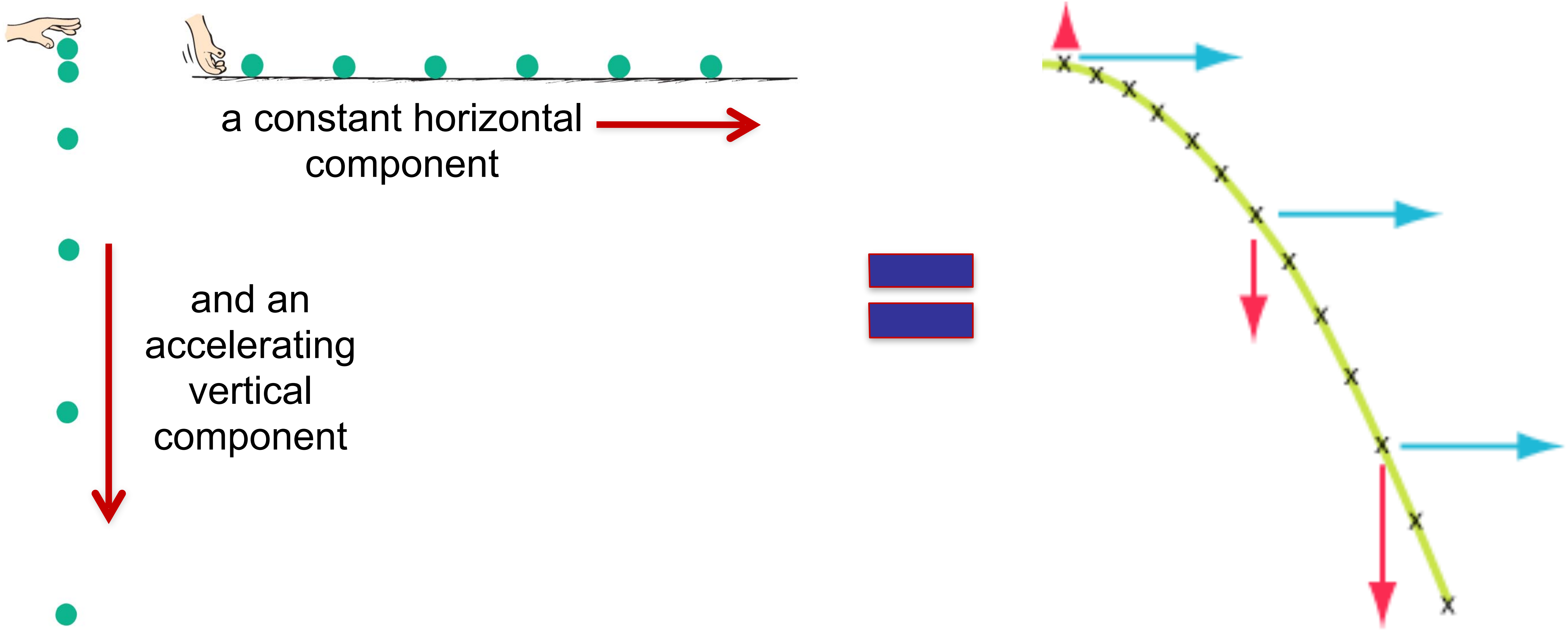
Parabola:

The shape of the curved path of the projectile.



PROJECTILE MOTION

Projectile motion is a combination of:



PROJECTILE MOTION

Example:
An object at the edge of a cliff is shot horizontally with a speed of 10 m / s. Assume there's no air resistance. If the object is still in flight, what is its horizontal speed 4 seconds after it is shot?

What is its horizontal speed 9 seconds after it is shot?

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Answer:

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What is its horizontal speed 9 seconds after it is shot?

Answer:
Because a projectile always maintains a constant horizontal speed, its speed would still be 10 m/s regardless of time passed. At both times, the horizontal speed remains equal at 10 m/s.

PROJECTILE MOTION

Example:

An object at the edge of a cliff is shot horizontally with a speed of 10 m/s. Assume there's no air resistance. If the object is still in flight, what's its vertical speed 2 seconds after shot?

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Because its vertical speed depends only on gravity and time (and it's independent of the horizontal speed), the speed after 2 seconds would be :

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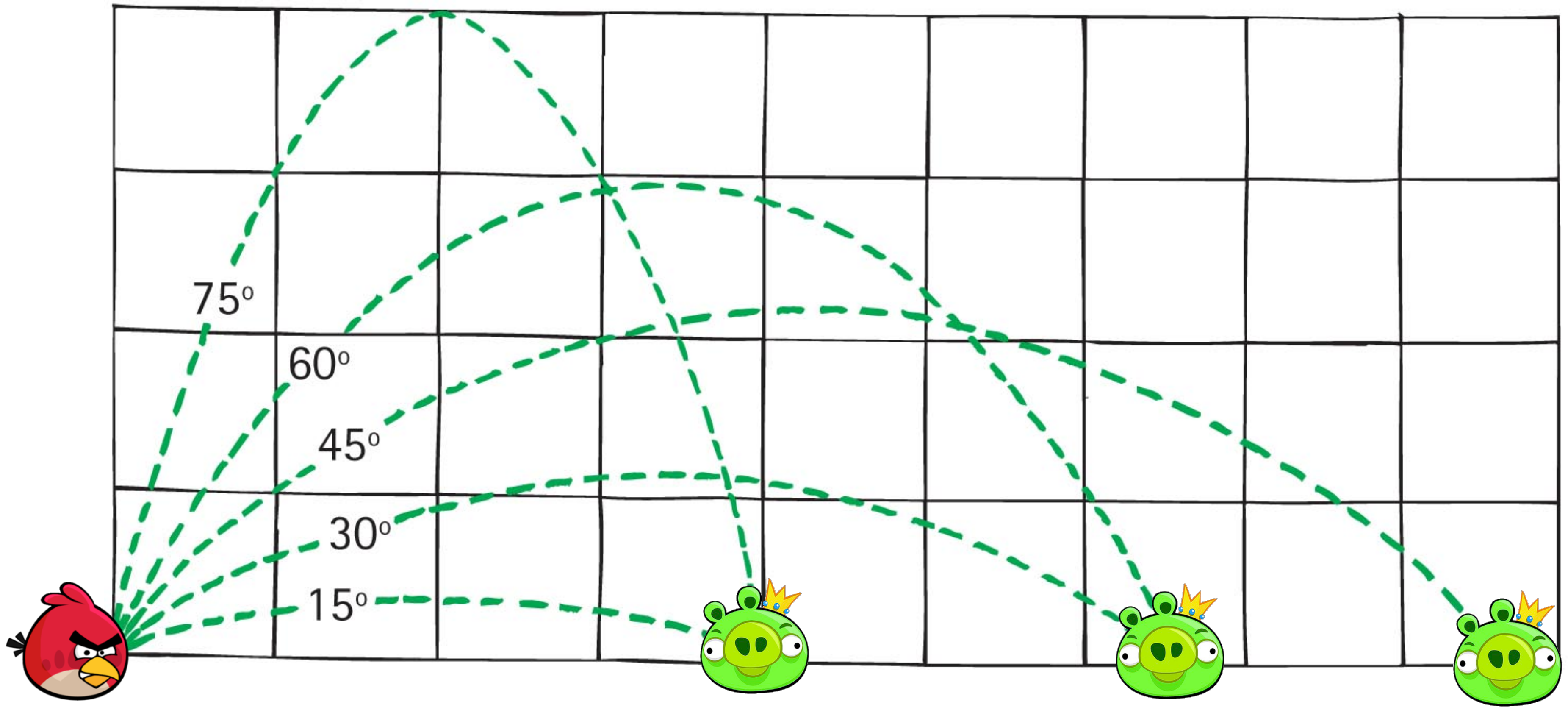
Answer:
Because its vertical speed depends only on gravity and time (and it's independent of the horizontal speed), the speed after 2 seconds would be :

$$v_{vertical} = (g)(t) = \left(9.8\frac{m}{s^2}\right)(2s) = 19.6\frac{m}{s}$$

PROJECTILE ALTITUDE AND RANGE

For equal launch speeds, the same range is obtained from two different projection angles:

COMPLEMENTARY ANGLES → Two angles that add up to 90°



$75° + 15° = 90°$

$60° + 30° = 90°$

$45° + 45° = 90°$

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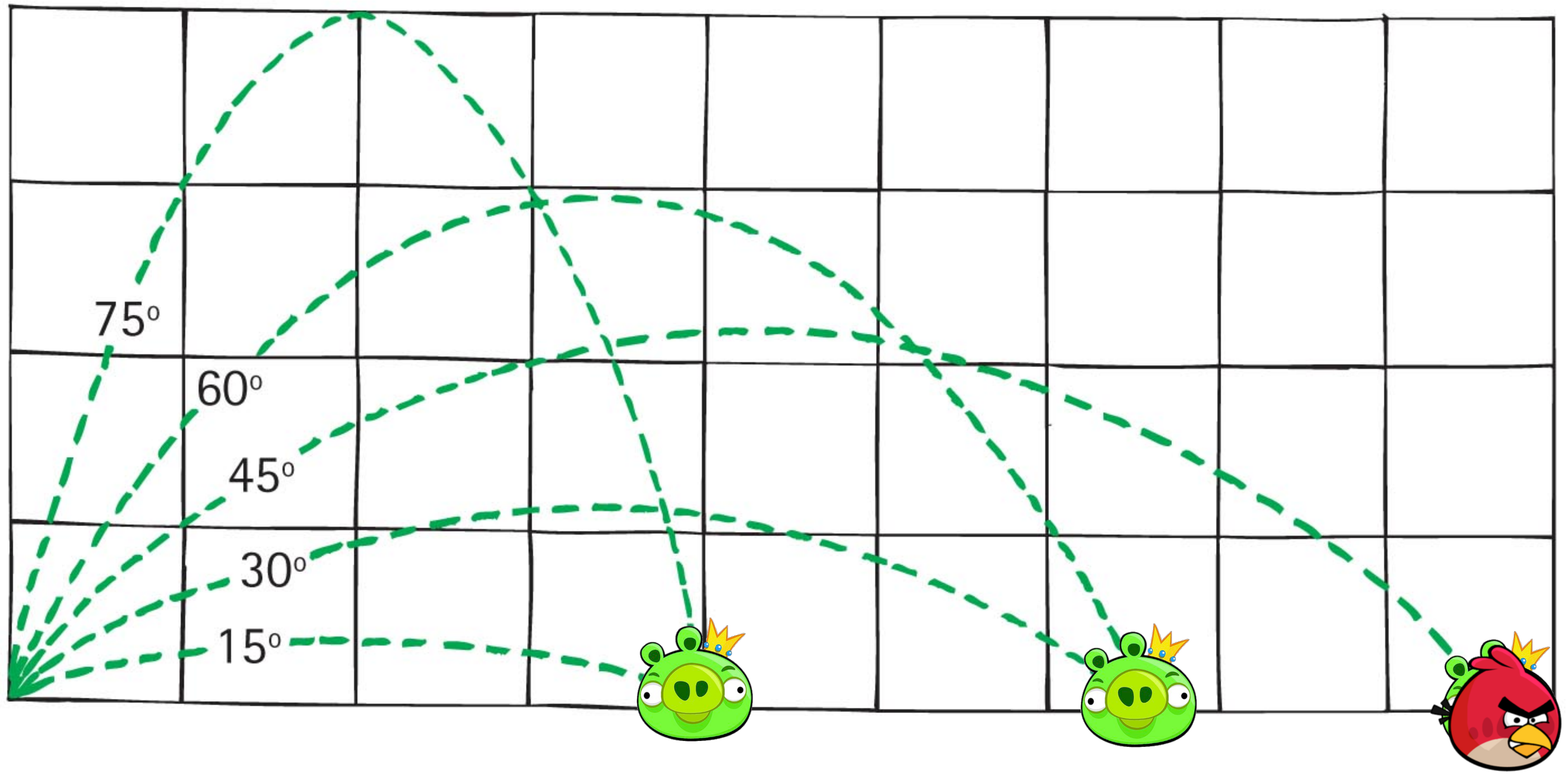

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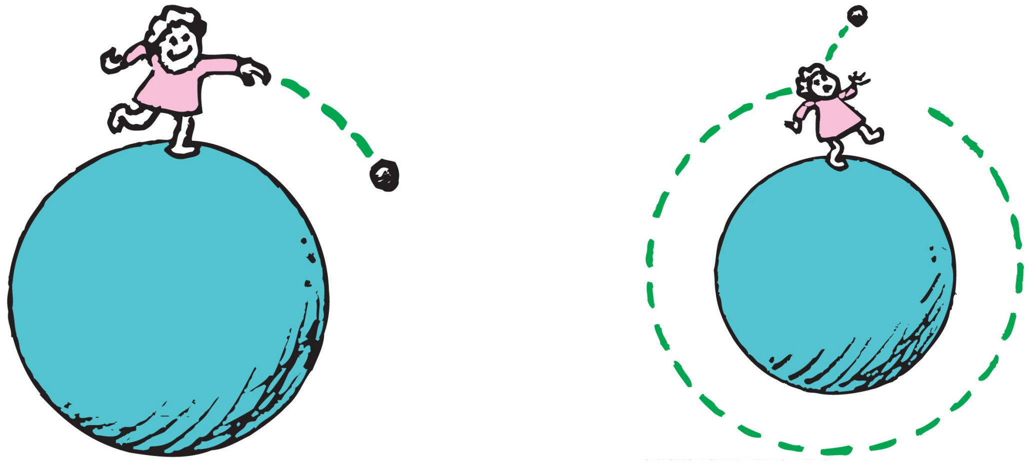
FAST-MOVING PROJECTILES — SATELLITES

A satellite is any projectile moving fast enough to fall continually around the Earth.

To become an Earth satellite, the projectile's horizontal velocity must be great enough for its trajectory to match Earth's curvature.

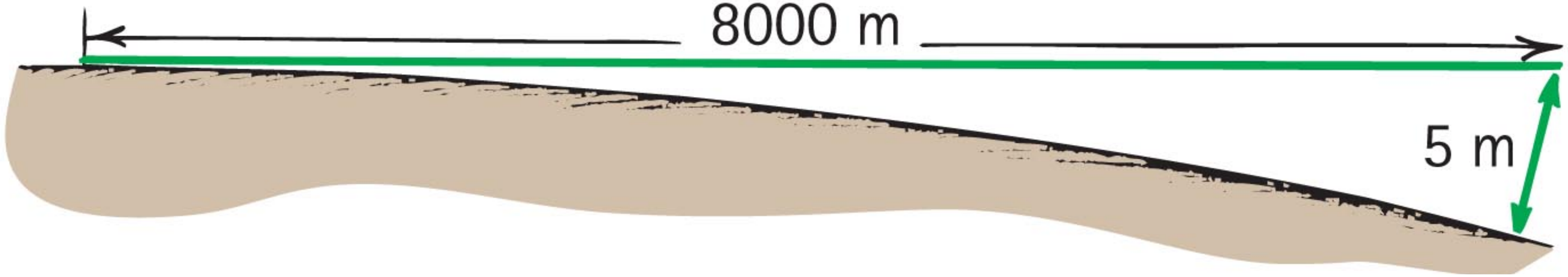


FAST-MOVING PROJECTILES—SATELLITES

The Earth's curvature drops a vertical distance of 5 m for each 8,000 m tangent to the surface.

So to orbit Earth, a projectile must travel 8,000 m in the time it takes to fall 5 m.

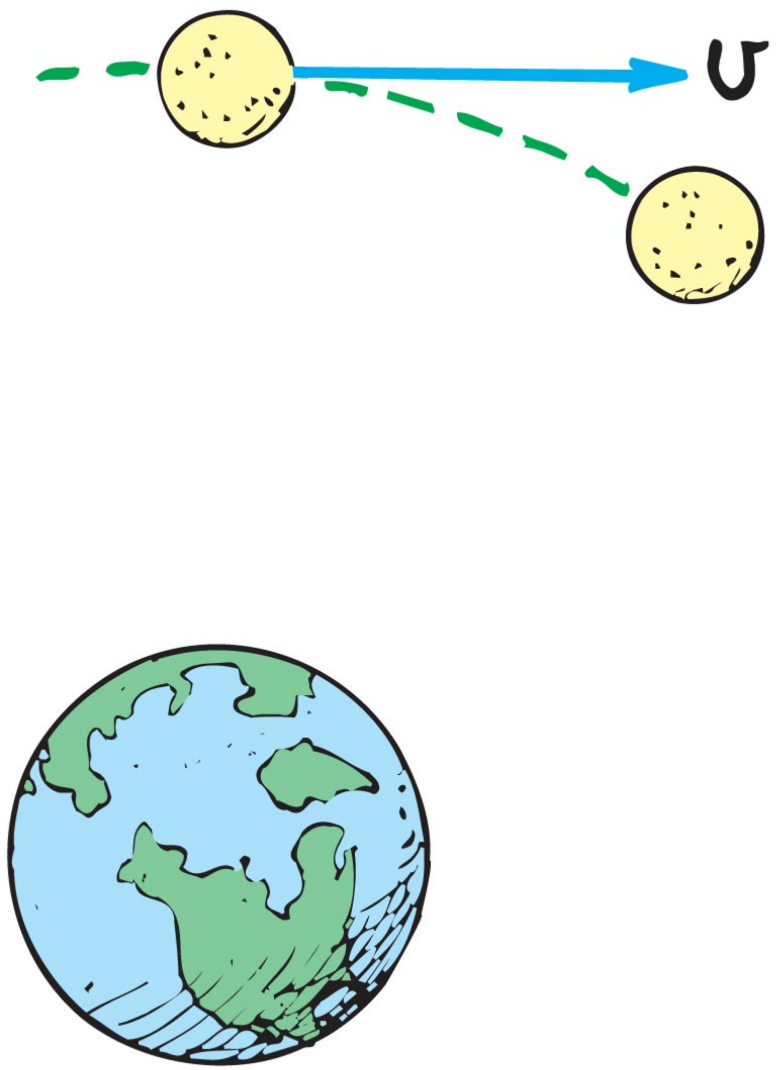
Therefore, the minimum speed a projectile must have to orbit the Earth is 8,000 m/s.



THE FACT OF THE FALLING MOON

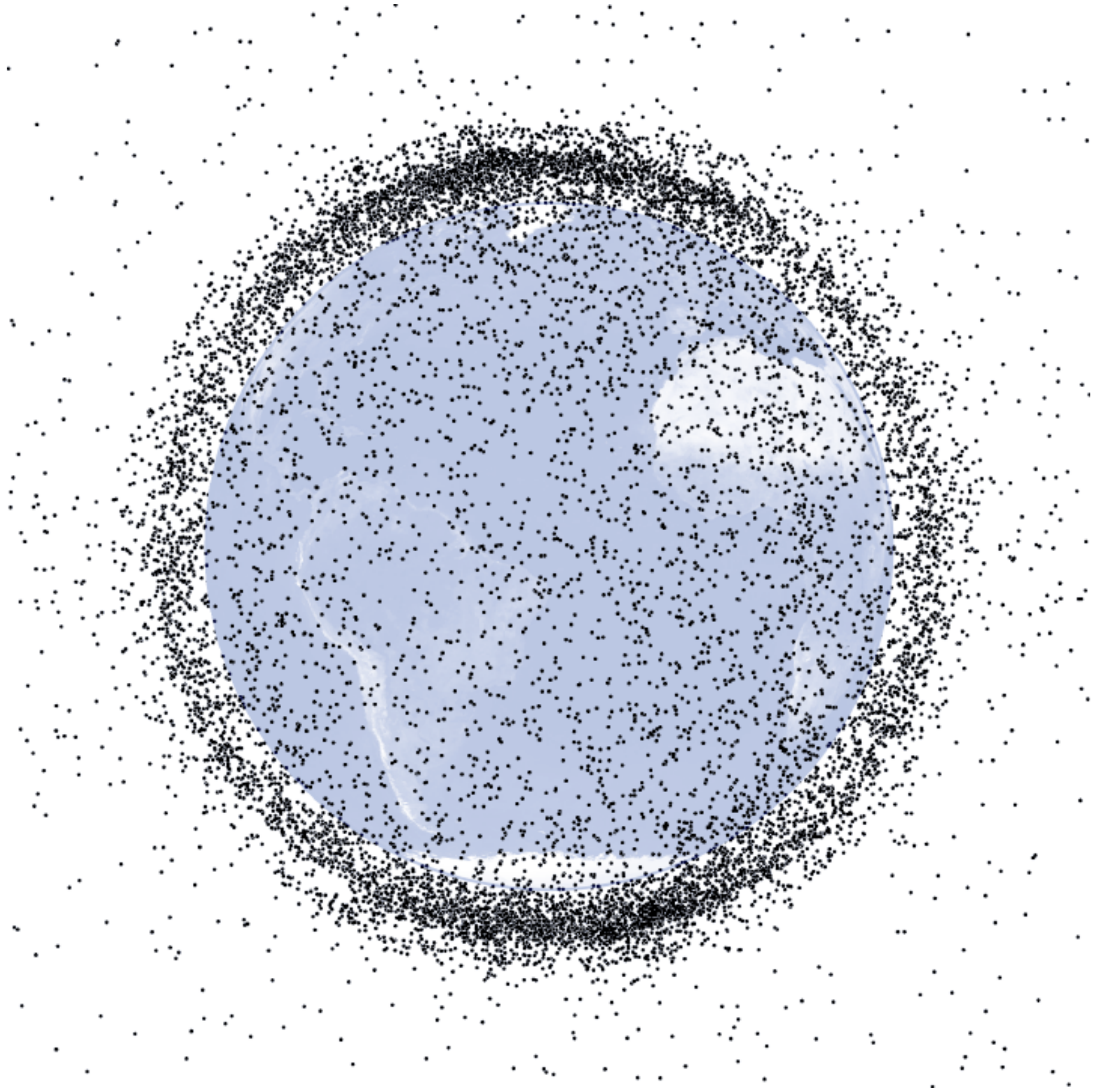
We now know that the Moon falls around Earth in the sense that it falls beneath the straight line it would follow if no force acted on it.

The Moon maintains a tangential velocity, which ensures a nearly circular motion around and around Earth rather than into it. This path is similar to the paths of planets around the Sun.

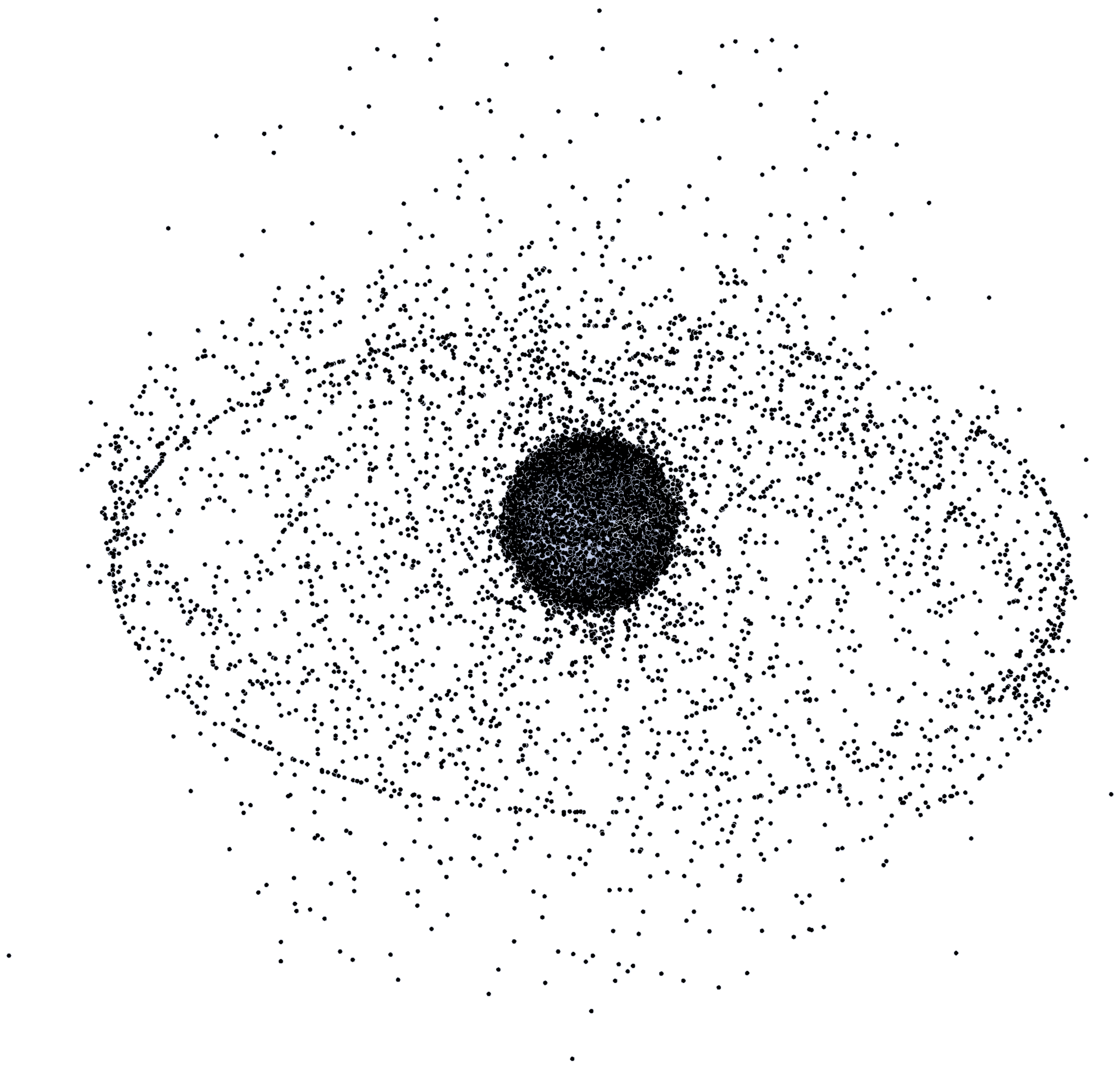


SPACE DEBRIS

Low Earth Orbit



High Earth Orbit



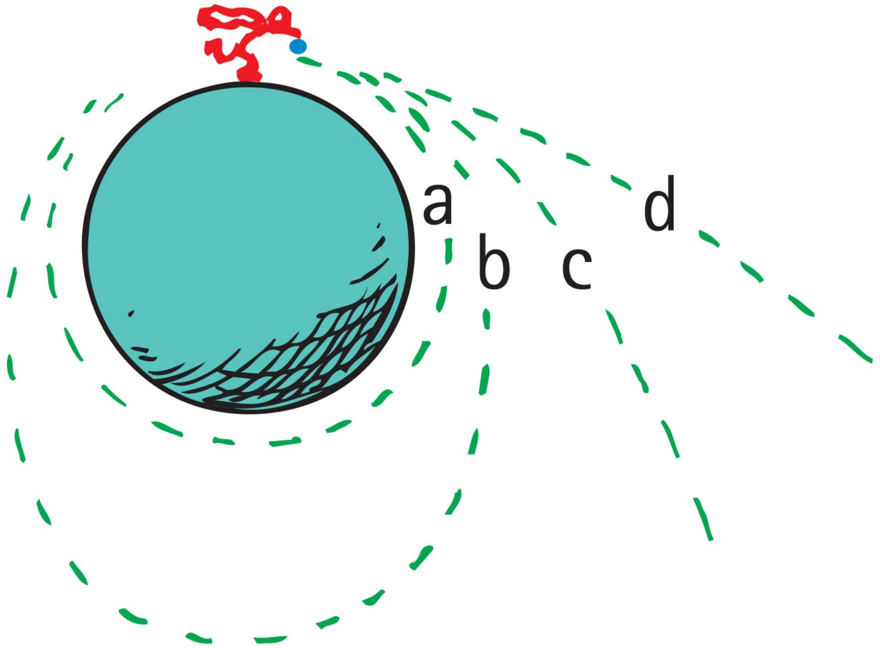
ESCAPE SPEED

Escape speed: the initial speed that an object must reach to escape gravitational influence of Earth or other celestial body.

11,200 m/s to escape Earth

42,500 m/s to escape Solar System

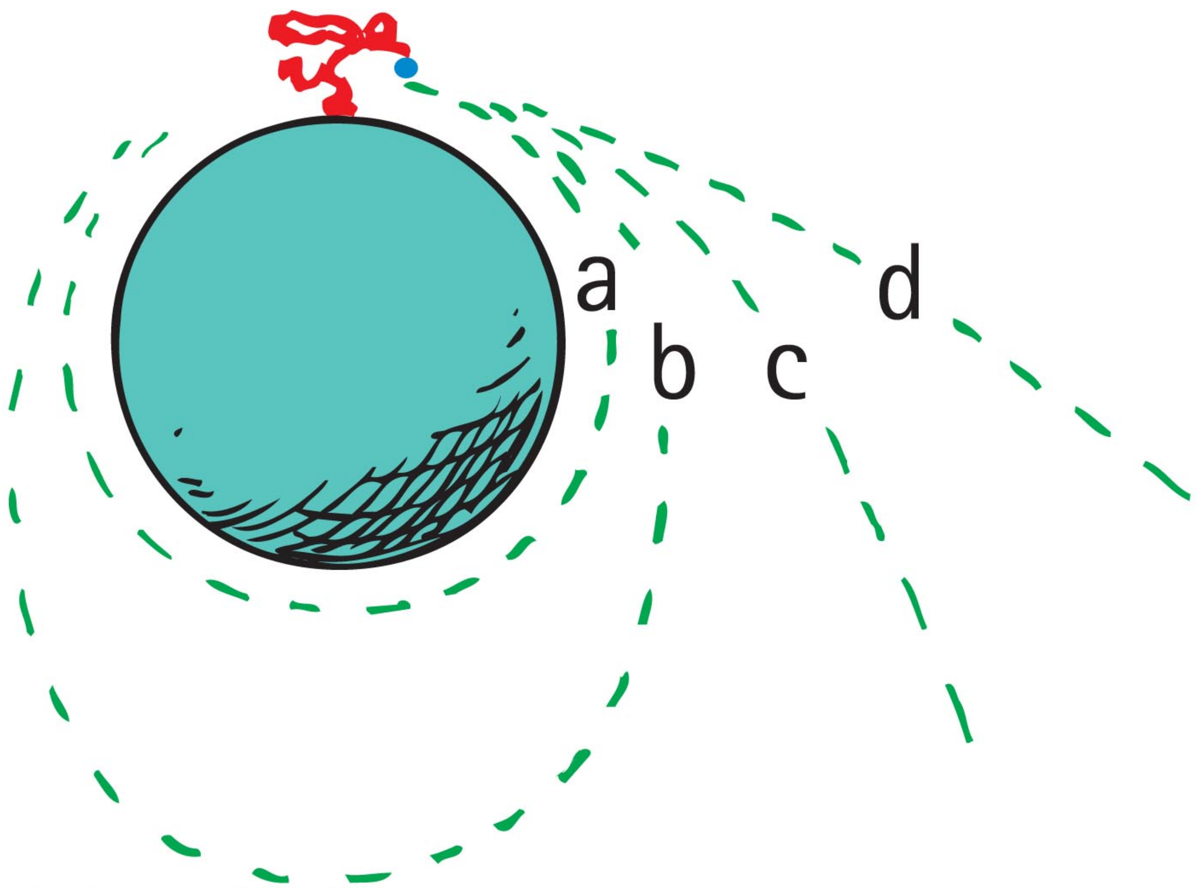
As speed of satellite approaches escape speed, orbit becomes more elliptical in shape with respect to the celestial body of reference.



SATELLITES AND ESCAPE SPEED

Ex: Match each of the orbits with one of the following speeds:

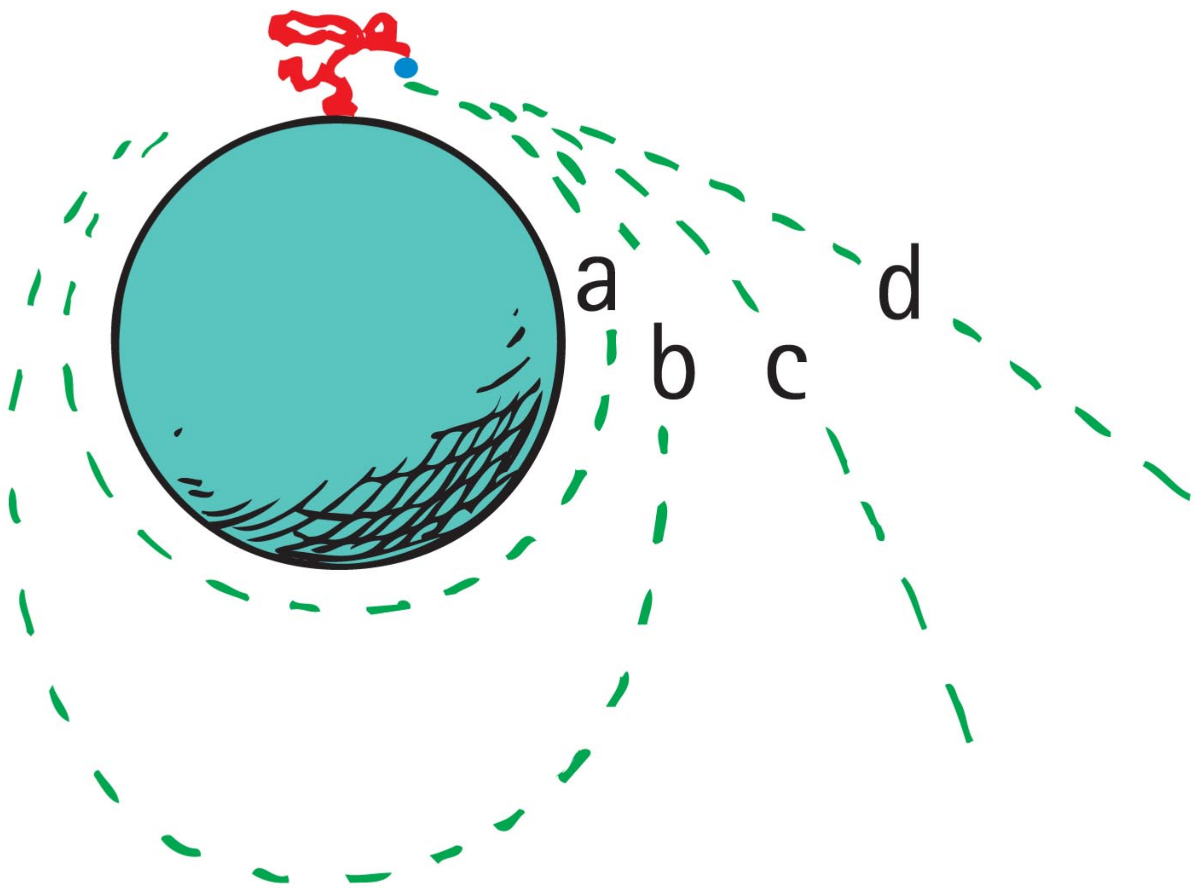
1) 11,200 m / s
2) 8,000 m / s
3) 42,500 m / s
4) 9,000 m / s



SATELLITES AND ESCAPE SPEED

Ex: Match each of the orbits with one of the following speeds:

1) 11,200 m / s
2) 8,000 m / s
3) 42,500 m / s
4) 9,000 m / s



Answers:

SATELLITES AND ESCAPE SPEED

Ex: Match each of the orbits with one of the following speeds:

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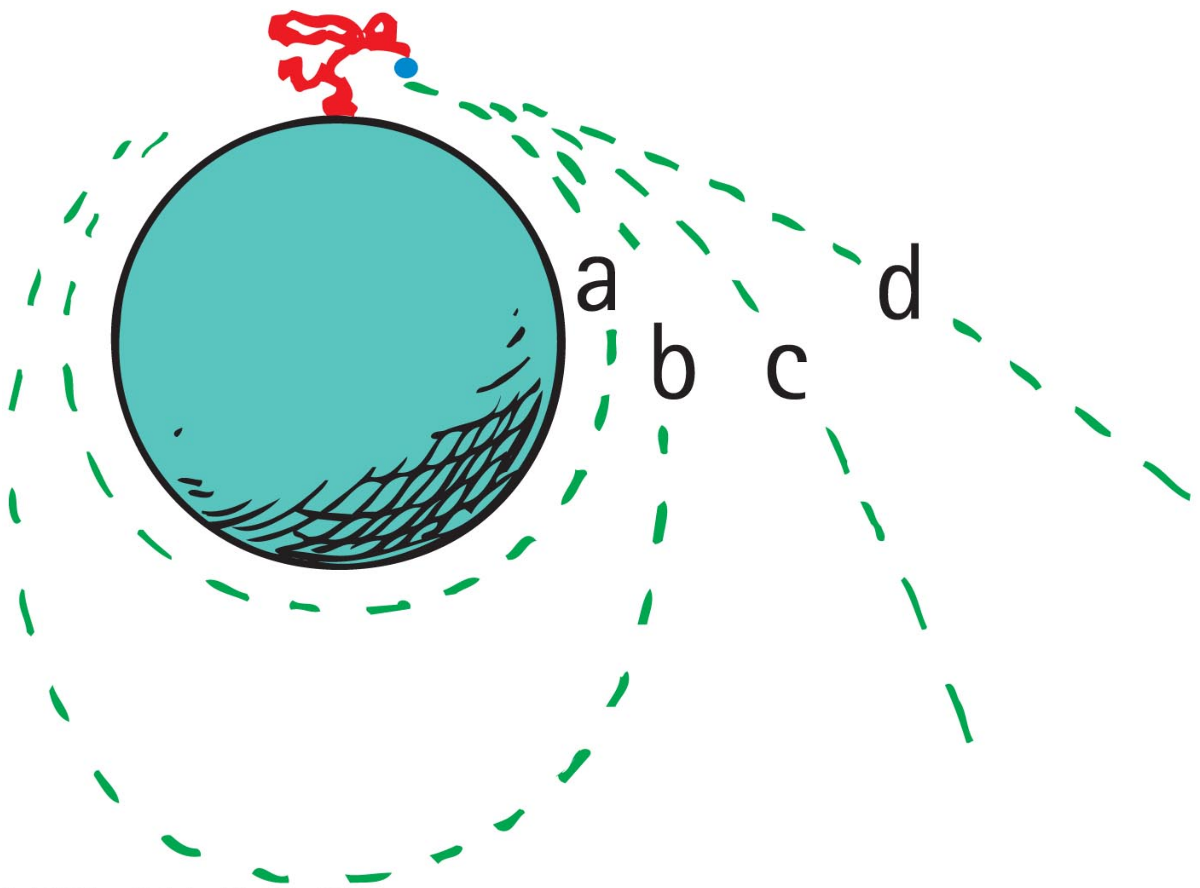


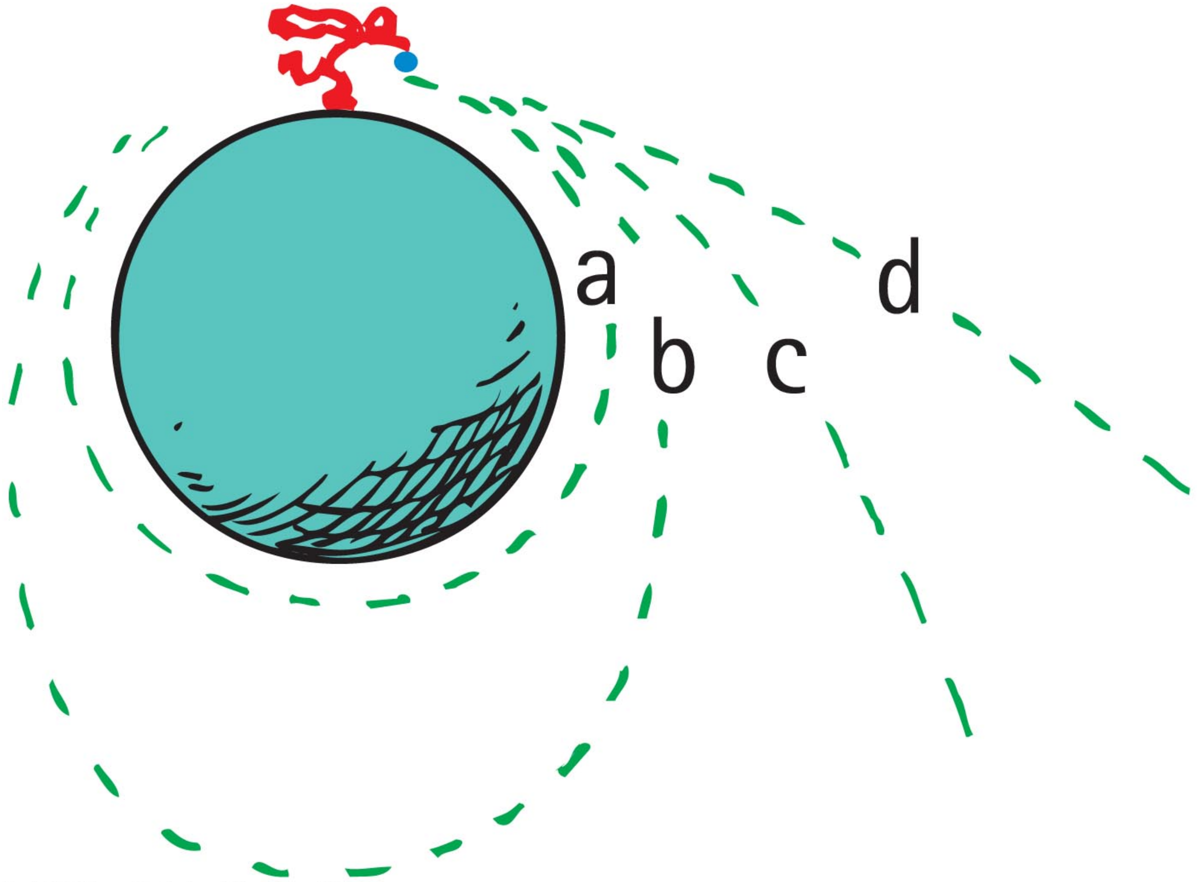
Answers:

1) c

SATELLITES AND ESCAPE SPEED

Ex: Match each of the orbits with one of the following speeds:

1) 11,200 m / s
2) 8,000 m / s
3) 42,500 m / s
4) 9,000 m / s



Answers:

1) c
2) a

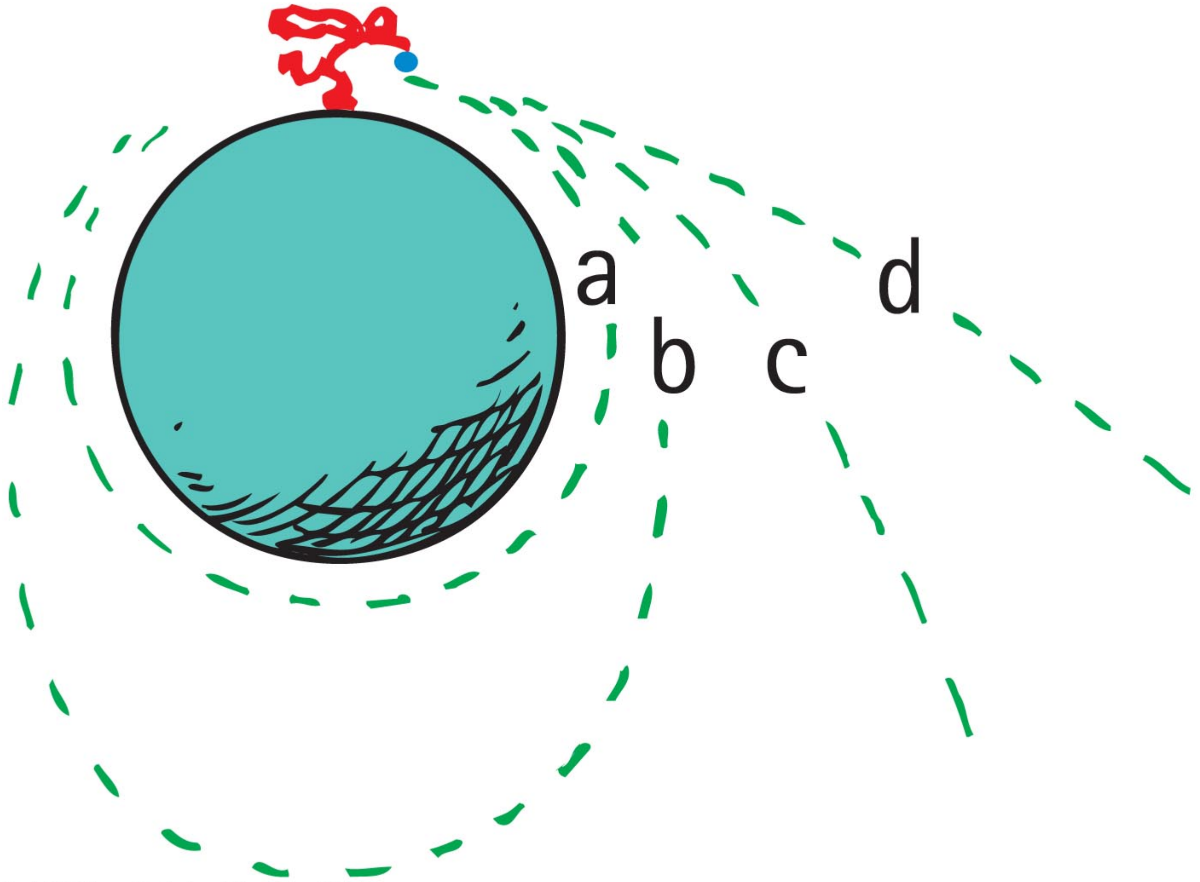
SATELLITES AND ESCAPE SPEED

Ex: Match each of the orbits with one of the following speeds:

1) 11,200 m / s
2) 8,000 m / s
3) 42,500 m / s
4) 9,000 m / s

Answers:

1) c
2) a
3) d



SATELLITES AND ESCAPE SPEED

Ex: Match each of the orbits with one of the following speeds:

1) 11,200 m / s
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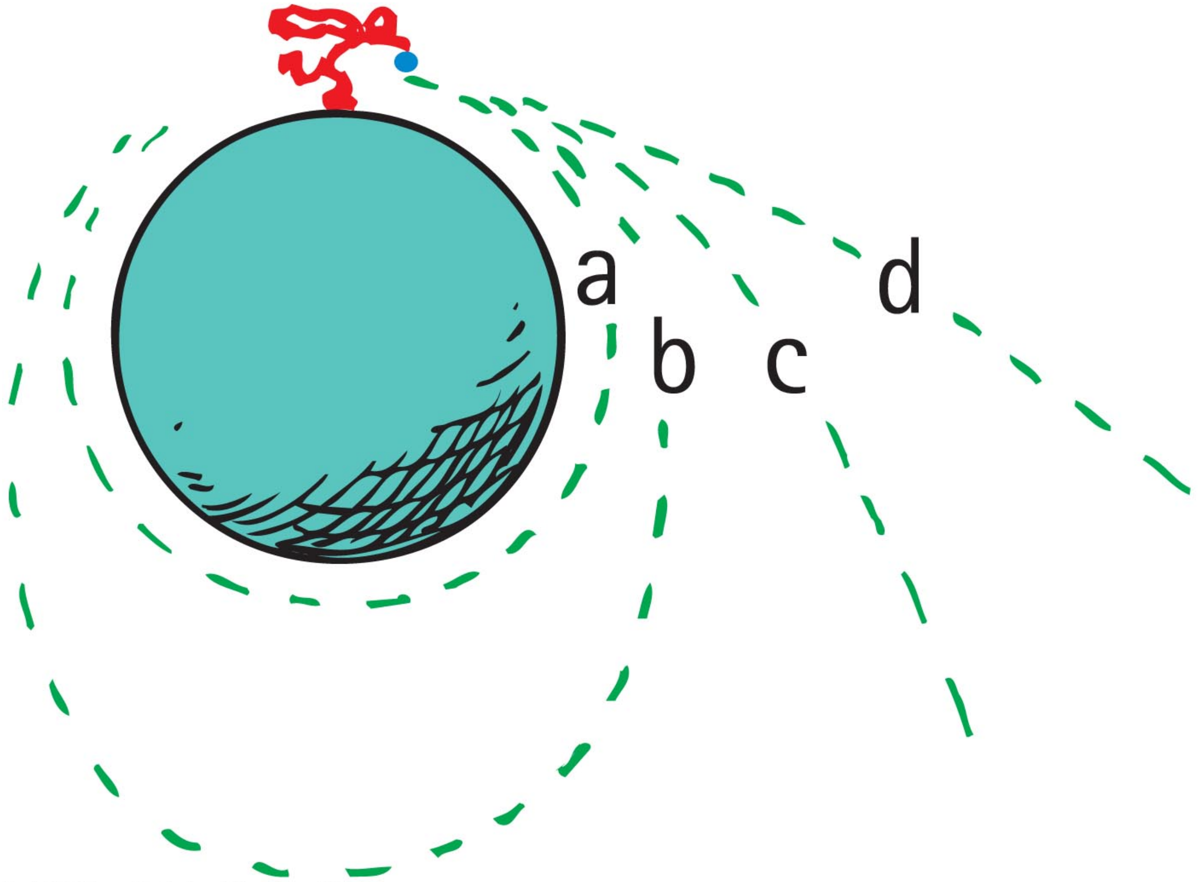

Answers:

1) c
2) a
3) d
4) b