Newton's Law of Universal Gravitation

Law of Universal Gravitation:

Every object attracts every other object with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

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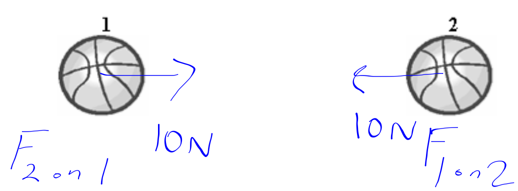
Two identical basketballs are floating in deep space.



a) What will happen?

move together w/increasing accl

b) If basketball #1 pulls on basketball #2 with a force of 10. N, how strongly does basketball #2 pull on basketball #1?

c) Explain this behavior using one of Newton's laws of motion.

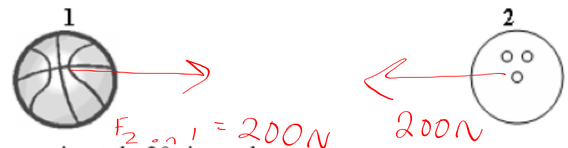
3rd Law

d) Compare the accelerations of the two basketballs.

same

$F = ma$

Basketball #2 is now replaced with a bowling ball.



e) If the mass of the bowling ball is approximately 20 times the mass of the basketball, how strong is the new force pulling on basketball #1?

f) How much force does the basketball exert on the bowling ball?

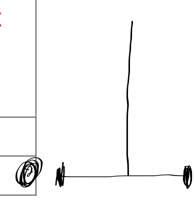
g) Compare the accelerations of the two balls.

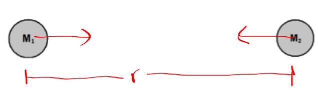
F is same

$m \cdot a = m\, a$

Calculating the Force of Gravity IB 11

Variable	Fg	G	m	r
Quantity	force of gravity weight	universal grav. constant $G = 6.67 \times 10^{-11}$	mass	center to center dist
Units	[N]	$[N\,m^2/kg^2]$	[kg]	[m]
Type				

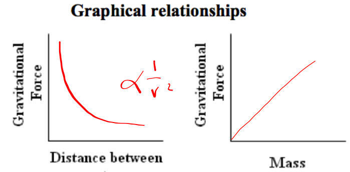




Formula

$$F_g = \frac{G m_1 m_2}{r^2}$$

Graphical relationships



inverse square law:

1. Calculate the gravitational force of attraction between a basketball and a bowling ball that are 1.50 meters apart.

$m = .625\,kg$ $\quad m = 5.00\,kg$

$F_g = \frac{GMm}{r^2}$

$= \frac{6.67\times10^{-11}\,N\,\frac{m^2}{kg^2}\cdot 5\,kg \cdot .625\,kg}{(1.5\,m)^2} \approx 9.3\times10^{-11}\,N$

2. Calculate the force holding the Moon in orbit around the Earth.

$m \sim 10^{22}$ $\quad m \sim 10^{24}$

3. a) Calculate the gravitational force of attraction between you and the Earth.

$F_g = \frac{G M_E M_{me}}{r^2}$

$= \frac{6.67\times10^{-11}\,N\,\frac{m^2}{kg^2}\; 5.97\times10^{24}\,kg \; 70\,kg}{(6.37\times10^6\,m)^2}$

b) For an object on or near the surface of a planet . . . $R_p \sim r$

c) What is another name for this force? Demonstrate this.

$F_g = mg$

$70\,kg \cdot 9.8\,m/s^2 = 686\,N$

4. a) What is the gravitational force of attraction between a 70. kilogram student and the Earth if the student is in a plane at an altitude of 6.37×10^6 m?

$\frac{686\,N}{4}$

b) When an object is above the surface of a planet . . . . $r = R_p + \text{altitude}$

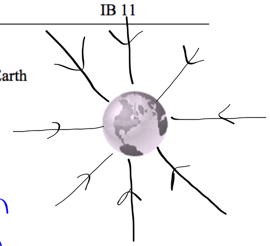
c) How could your answer to (a) be arrived at by proportional reasoning?

$\propto \frac{1}{r^2}$

Gravitational Field Strength IB 11

Gravitational field:
a region of space where a mass experiences a grav. force

Sketch the gravitational field of the Earth



Gravitational Force	**Gravitational Field Strength**
$\vec{F_g} = m\vec{g}$	$\vec{g} = F/m$
$\vec{F_g} = \frac{GM}{r^2} m$	$\vec{g} = \frac{GM}{r^2}$

Variable	Fg	G	g
Quantity	weight Force of grav.	universal Grav. Constant	accl. due to grav Grav. field strength
Units	[N]	[Nm²/kg²]	[m/s²] or [N/kg]
Type	vector	scalar	vector
Property	varies	same everywhere	varies

1. Calculate the Earth's gravitational field strength:

a) at the surface of Earth.

$$\vec{g} = \frac{G M_E}{R_E^2}$$

$$\frac{6.67\times10^{-11}\,N\frac{m^2}{kg^2}\;5.97\times10^{24}\,kg}{(6.37\times10^{6}\,m)^2} = 9.8\,N/kg$$

b) at an altitude equal to one Earth radius.

$$\vec{g} \propto \frac{1}{r^2}$$

$$\frac{9.8\,N/kg}{4}$$

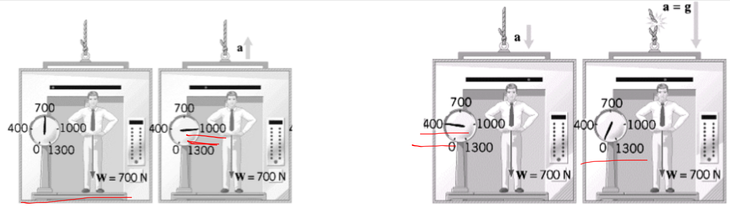
2. The International Space Station (ISS) orbits at an average altitude of 340 kilometers. How strong is the Earth's gravitational field at this altitude?

$$r = R_E + alt.$$
$$= 6.37\times10^{6}\,m + 0.34\times10^{6}\,m$$
$$= 6.71\times10^{6}\,m$$

3. Planet X has the same mass as Earth but only half the diameter. What is the gravitational field strength on the surface of this planet?

$$4\,g = \frac{GM}{(\frac{1}{2}R)^2}$$

Weight and Weightlessness - Riding in an Elevator



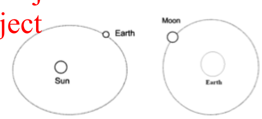
(*a*) No acceleration (v = constant) (*b*) Upward acceleration (*c*) Downward acceleration (*d*) Free-fall

1. When does the scale read the normal weight of the person?
2. When does the scale read higher than the normal weight of the person?
3. When does the scale read less than the normal weight of the person?
4. What does a scale reading actually measure?
5. Determine the acceleration of the elevator in cases (b) and (c).

Satellites IB 11

Satellite: an object that orbits another object

Natural Satellites



Artificial Satellites

1. How can an object become a satellite?

if it moves fast enough forward so that the Earth curves away underneath it at the same rate as it falls

2. What keeps a satellite up?

nothing! it keeps falling, just moving sideways fast enough

3. Why doesn't the Moon fall into the Earth as an apple does?

large enough tangential vel.

$g = 9.8\ m/s^2$

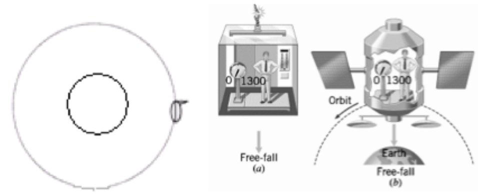
$a = \frac{v^2}{r}$

$v = \sqrt{r g}$

$= \sqrt{6.37 \times 10^6 m \cdot 9.8 m/s^2}$

Real weightlessness

Apparent weightlessness

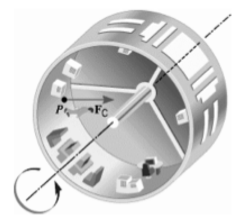


4. Why did the Apollo astronauts feel weightless?

5. Why do the space shuttle astronauts feel weightless?

Artificial Gravity

6. How can gravity be simulated in a space station?



7. How fast would this 20. meter diameter space station have to spin to simulate Earth's gravity?