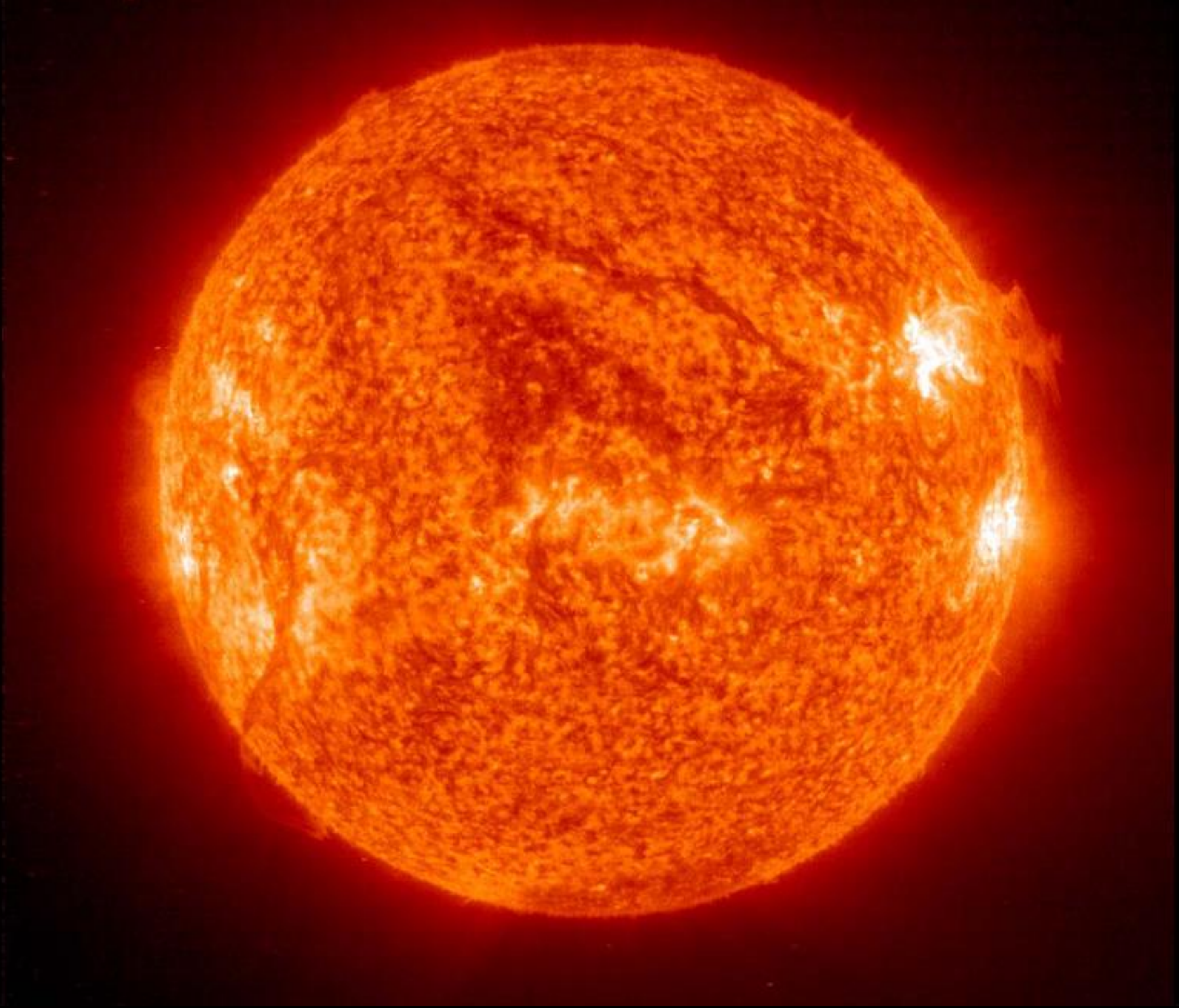
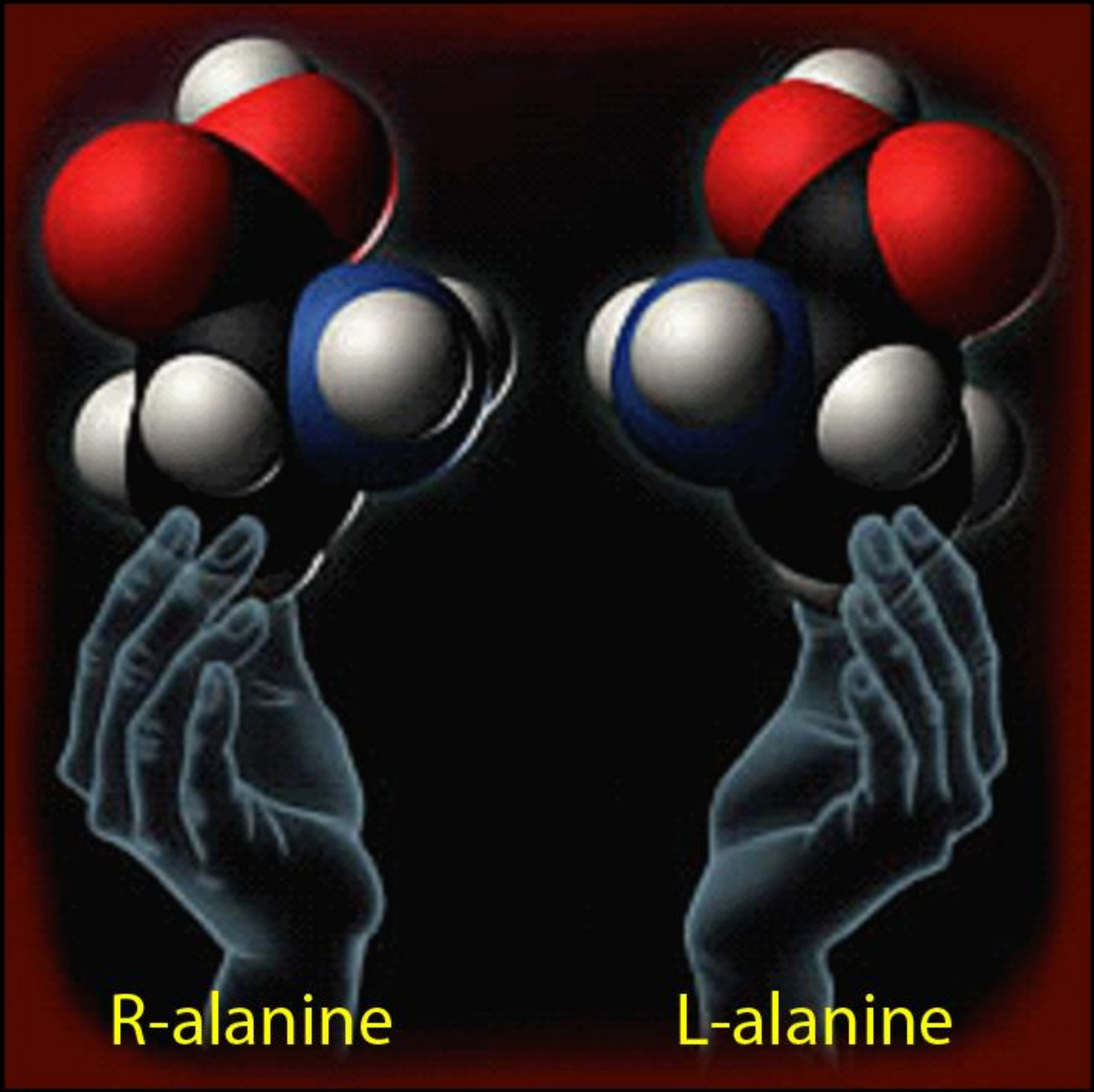
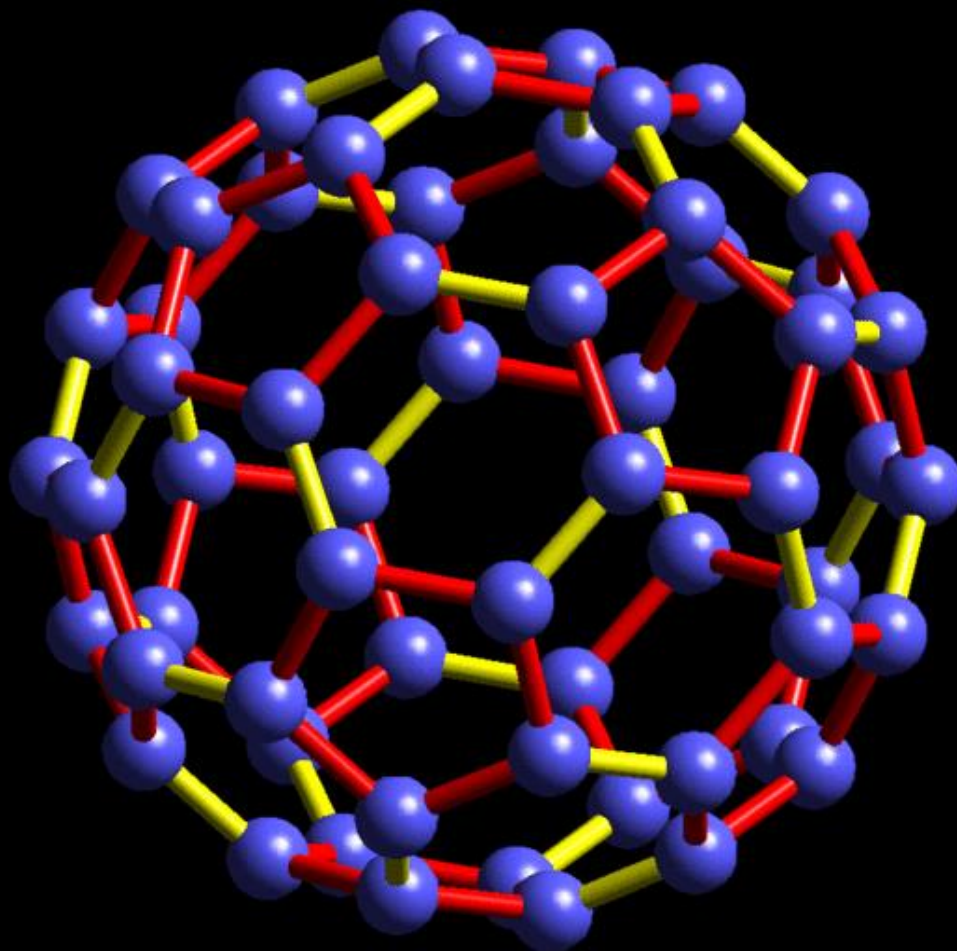
Four Fundamental Forces




R-alanine
L-alanine



C_{60}

Four Fundamental Forces

		range over space
macroscopic	Gravity	∞
	Electromagnetism	∞
subatomic	Strong Force	10^{-12} cm
	Weak Force	10^{-14} cm

Four Fundamental Forces

		strength
macroscopic	Gravity	1
	Electromagnetism	10^{42}
subatomic	Strong Force	10^{44}
	Weak Force	10^{38}

Four Fundamental Forces

Gravity: attracts mass

has an infinite range

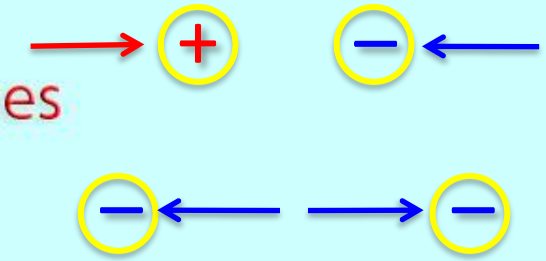
Four Fundamental Forces

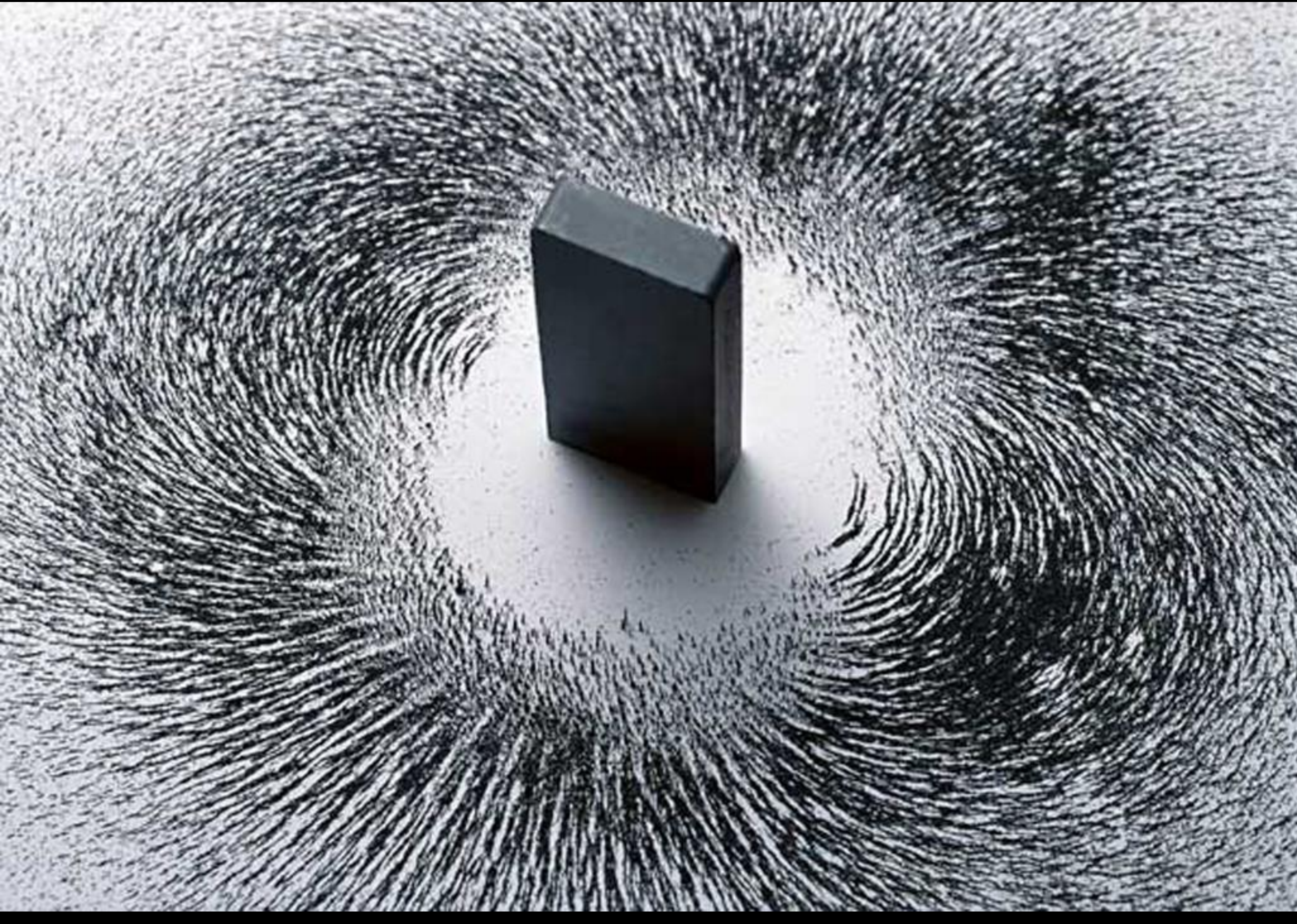
Electromagnetism:

attracts unlike charges

repels like charges

has infinite range



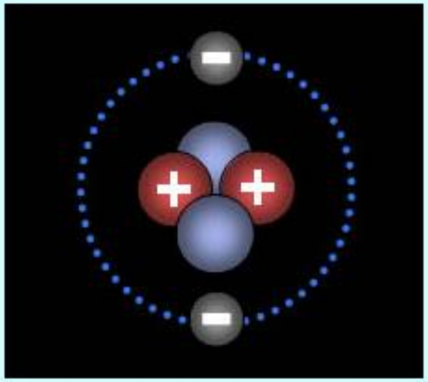


Four Fundamental Forces

Strong Force:

works on protons and neutrons

has a range of only 10^{-12} cm



1 it keeps protons and neutrons inside the atom . . .

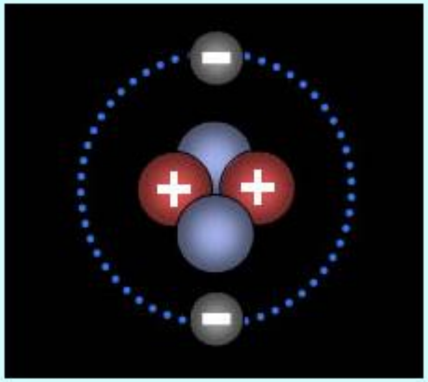
Hydrogen fusion bomb

Four Fundamental Forces

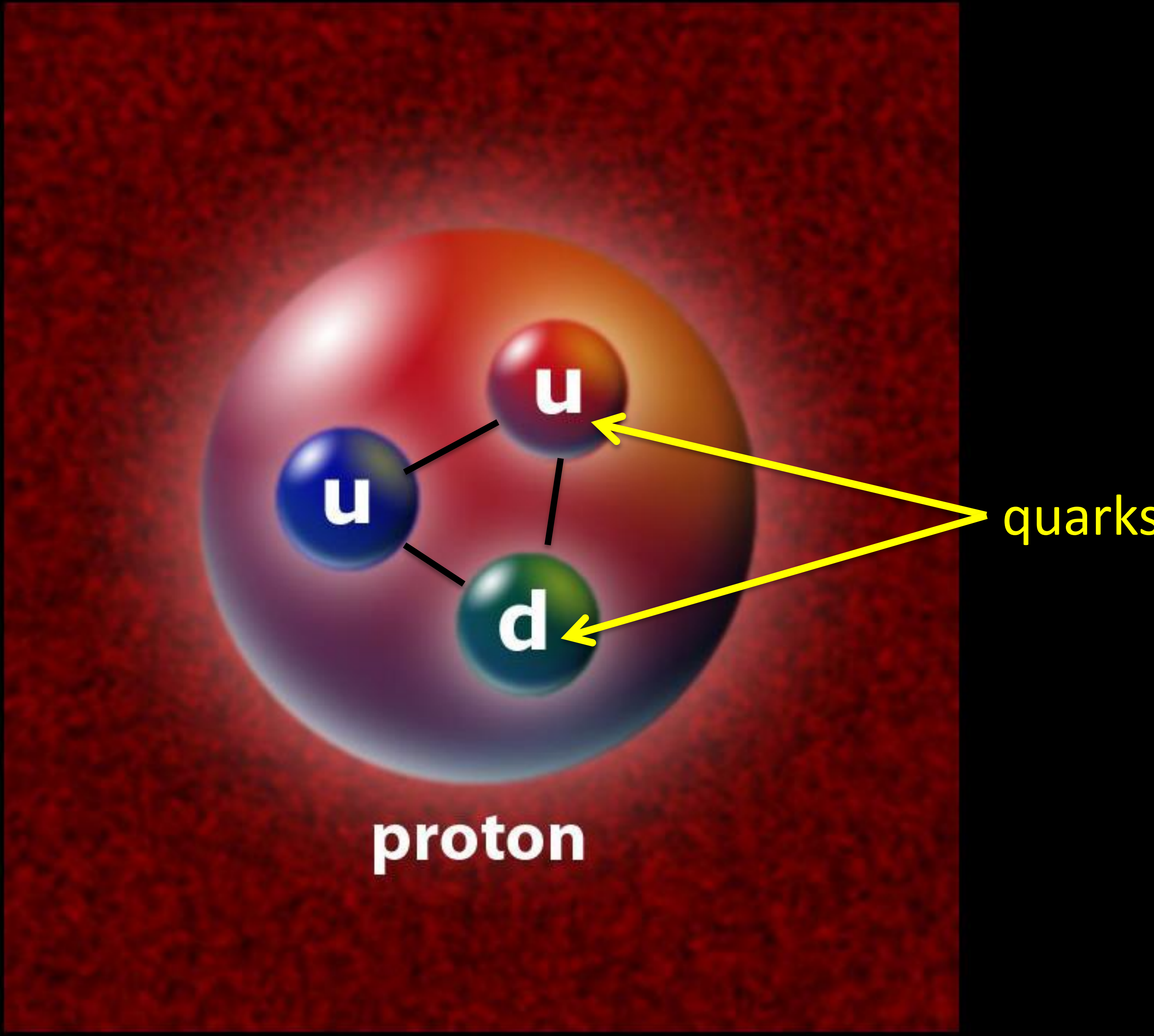
Strong Force:

works on protons and neutrons

has a range of only 10^{-12} cm



2 And it keeps quarks inside protons and inside neutrons

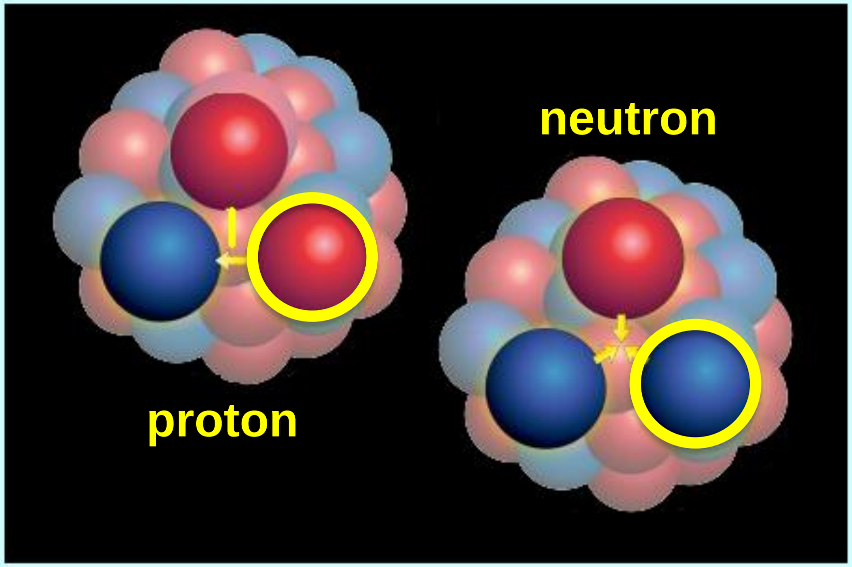

u
u
d
proton
quarks

Four Fundamental Forces

Weak Force:

turns p's into n's or n's into p's

has a range of 10^{-12} cm



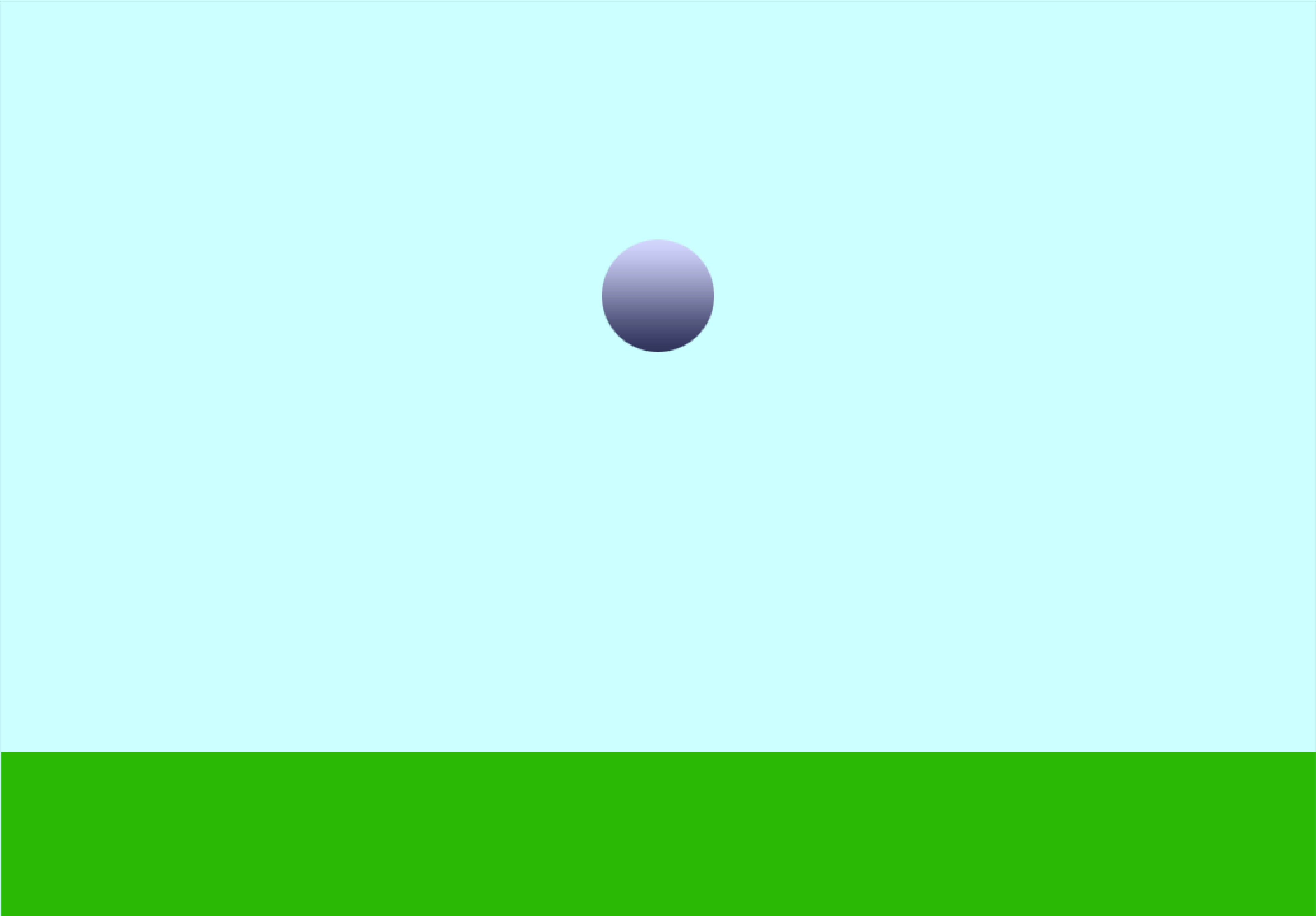
radioactivity

Nuclear Fission Plant

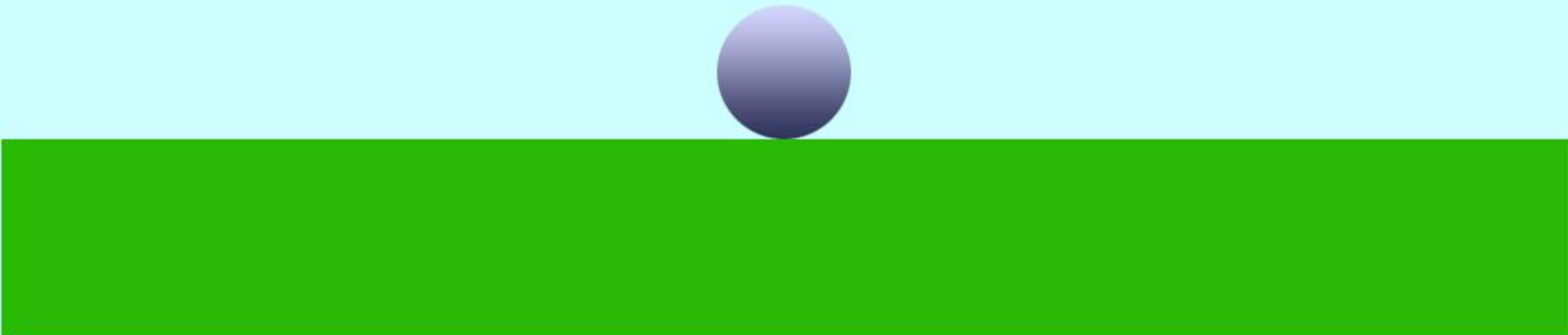
Atomic bomb

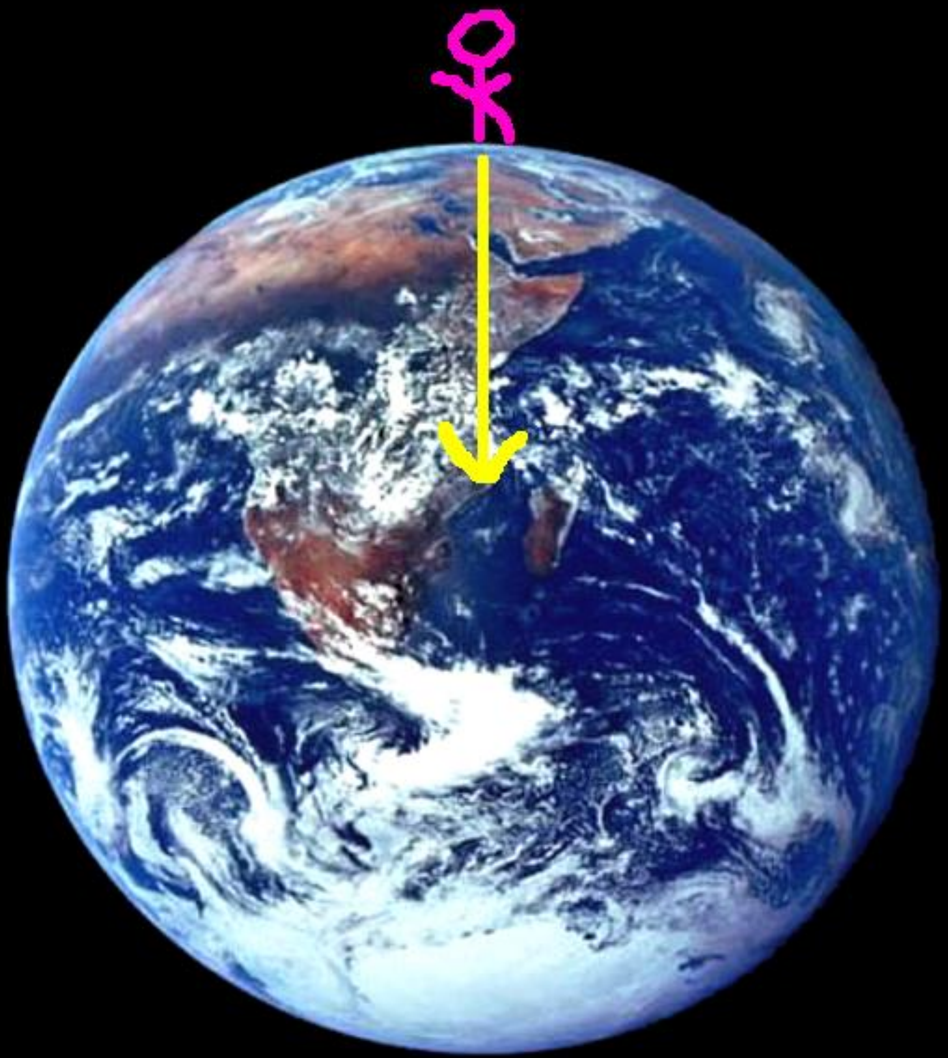
Force of Gravity


So what is keeping the astronaut
from falling to Earth?

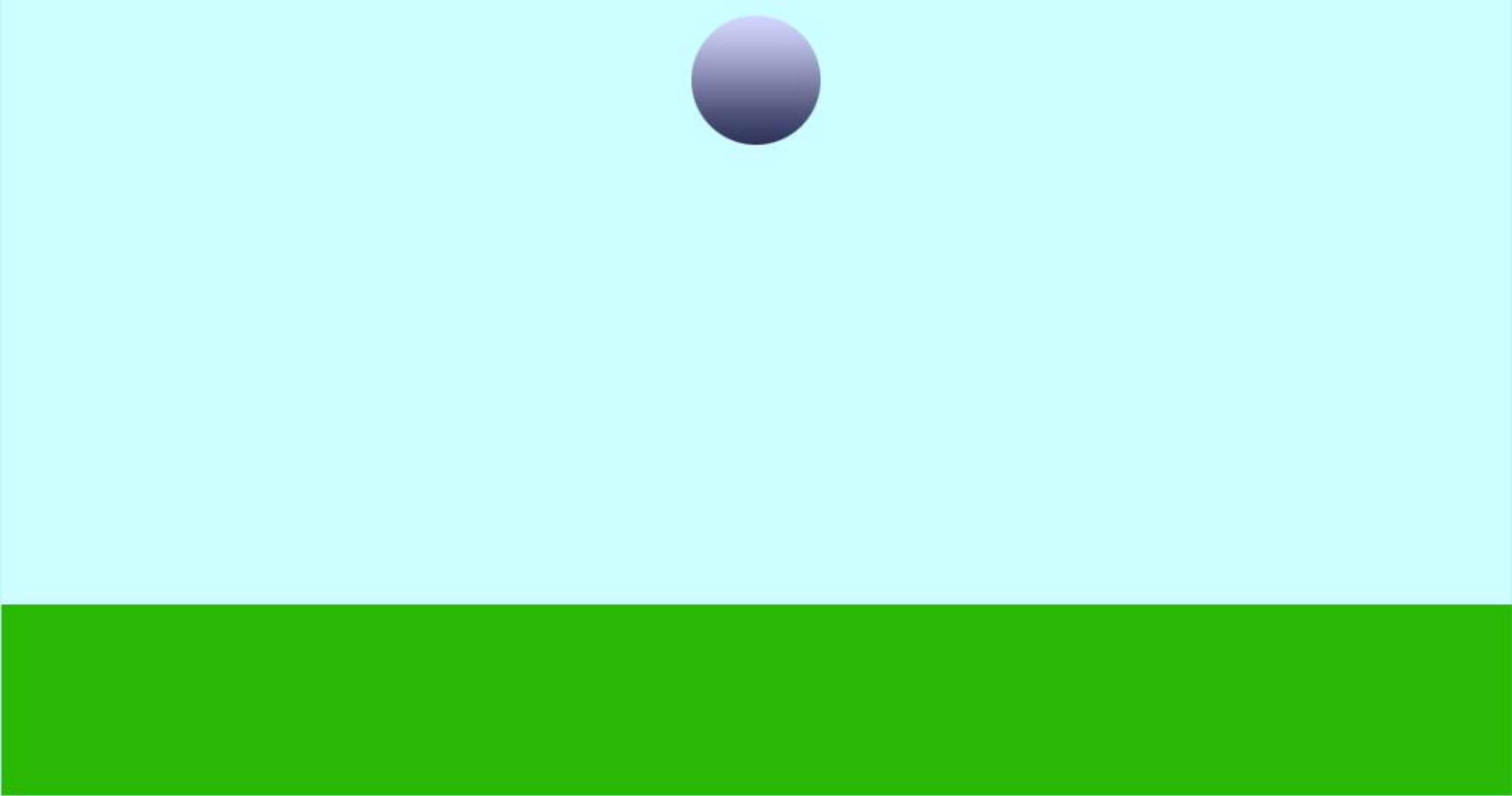


Gravity pulls down, only

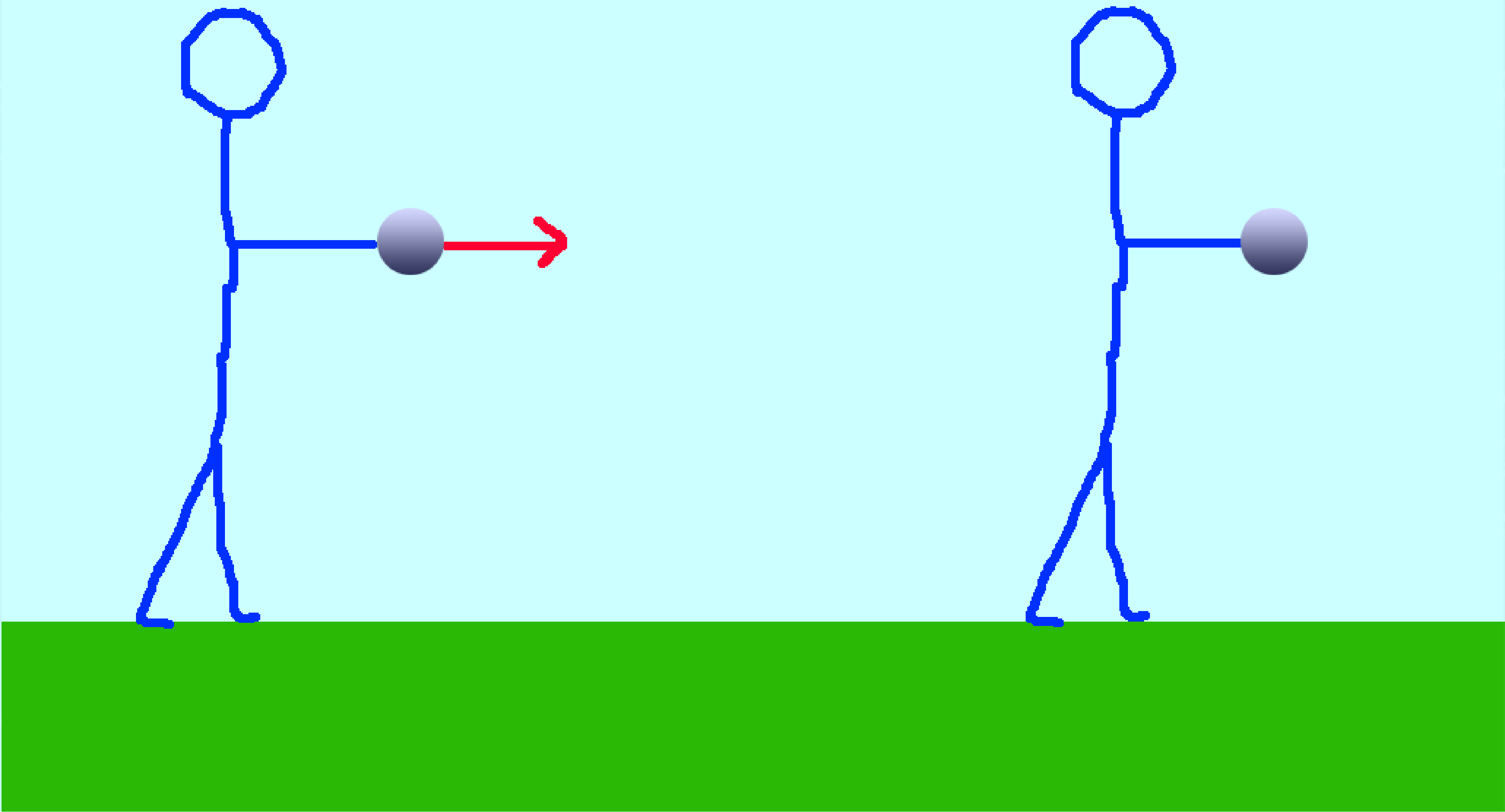




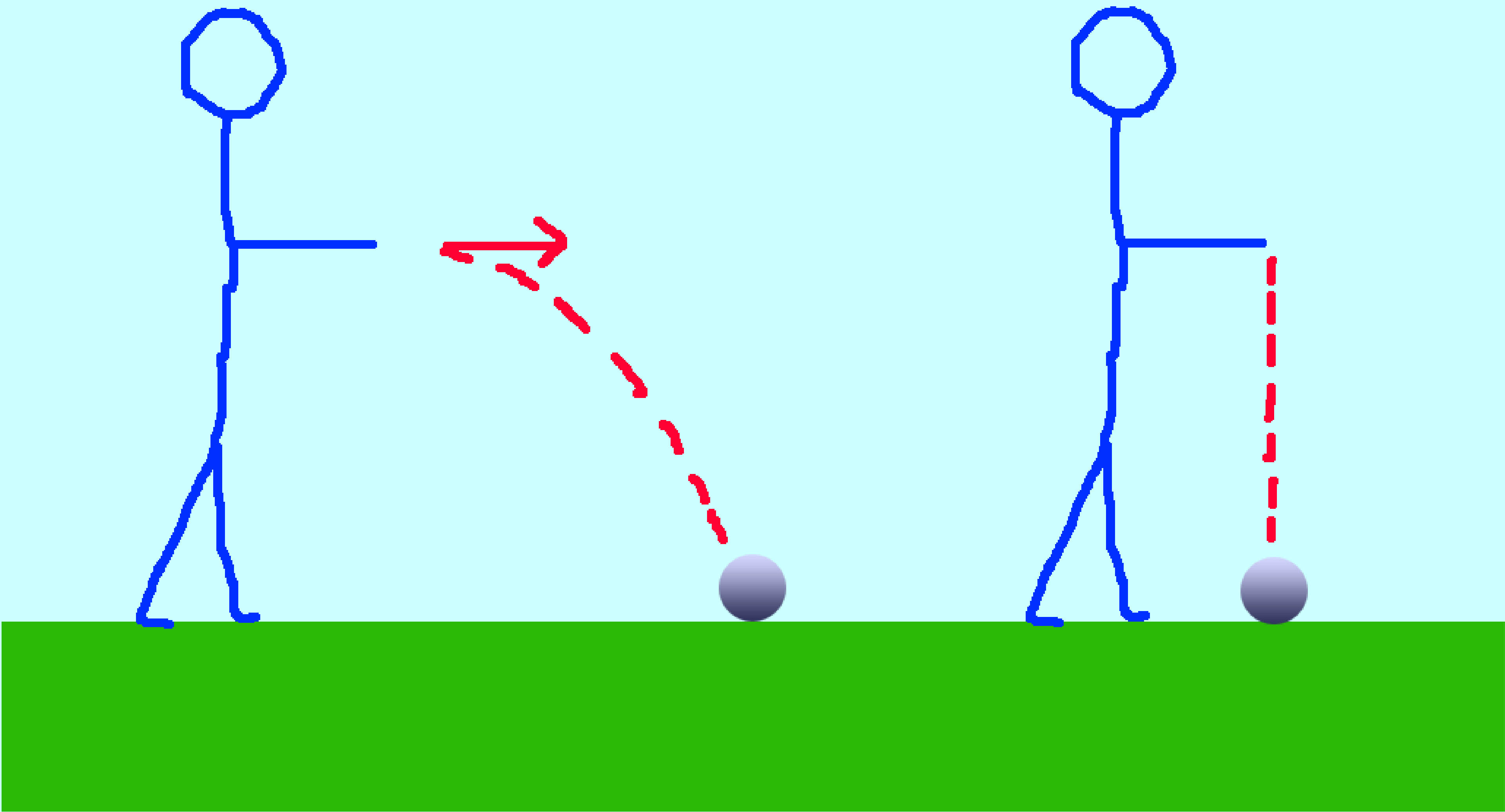
Gravity cannot affect sideways motion



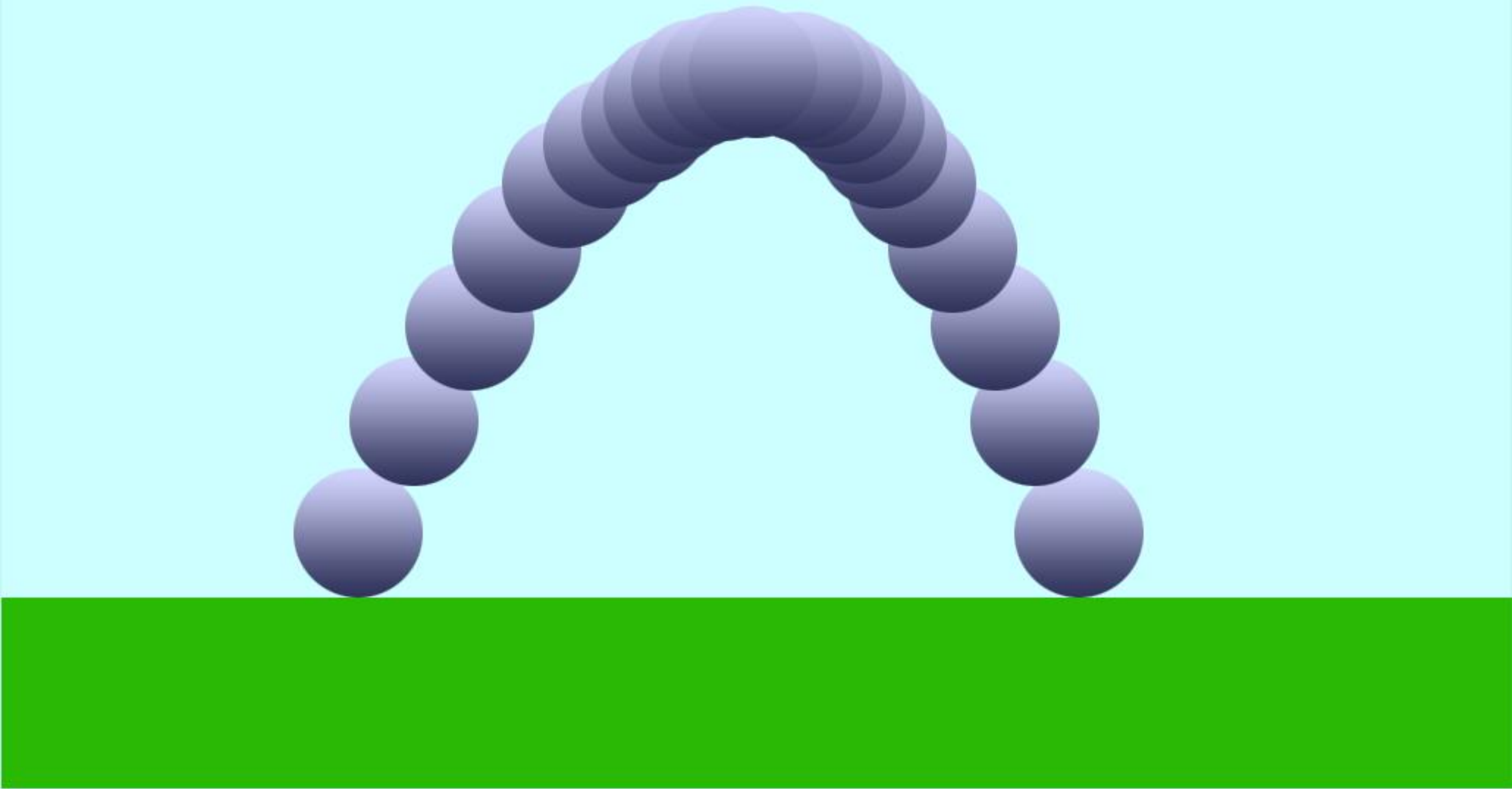
If one ball is thrown horizontal to the ground at the same time another is released from the same height....



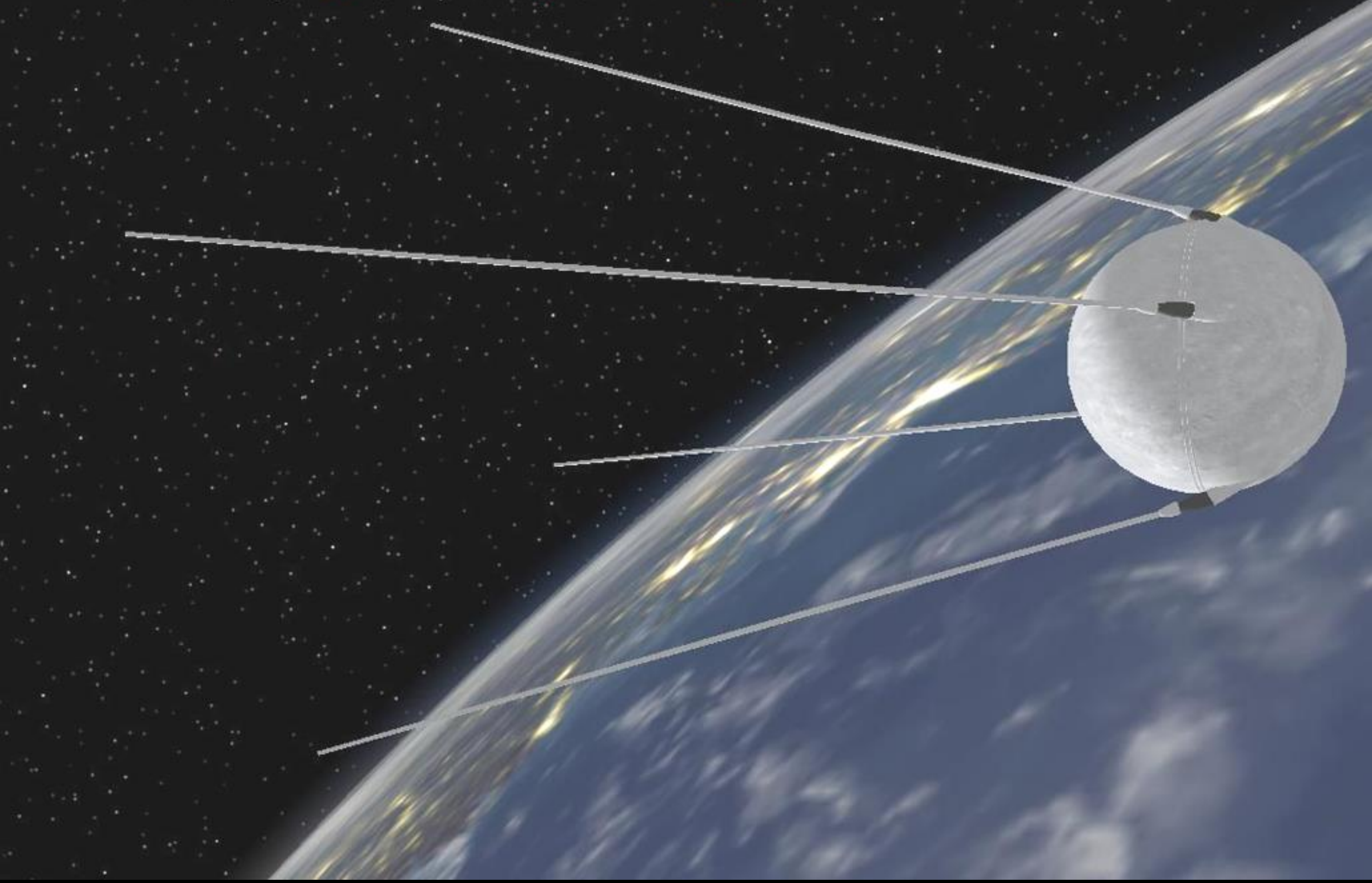
Both balls hit the ground
at the SAME TIME



and that is why a thrown ball flies through the air in a parabolic arc...



This is why we can put things in orbit.




Once an object reaches the right height and speed, it will go around and around the Earth without any engines firing.

So what is keeping the satellites from falling to Earth?

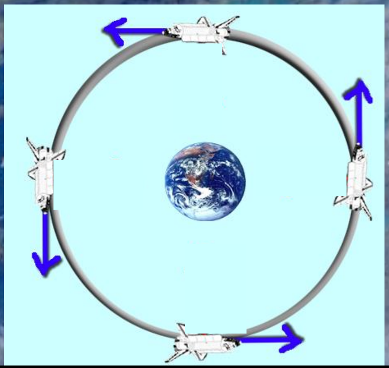
Once the satellite reaches a certain speed,

ORBITAL SPEED,

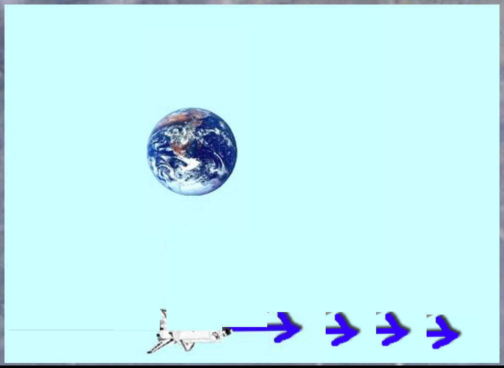
it misses Earth as it falls around it.

Objects in orbit are in free fall!

Since the natural direction of motion is a straight line, what makes the free-falling space shuttle turn around Earth?



versus



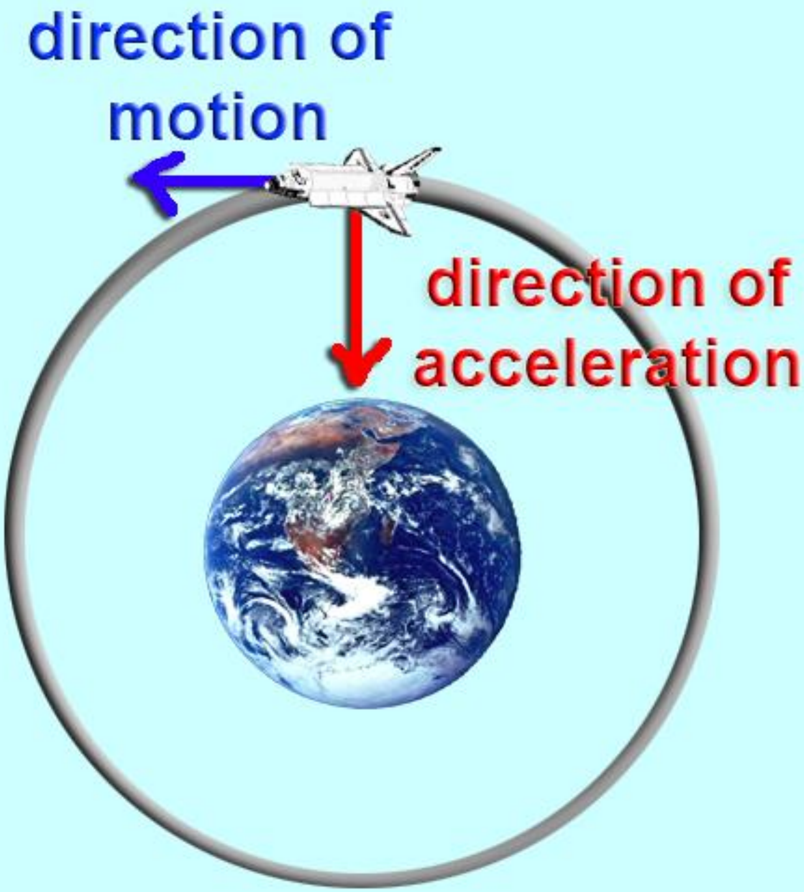
Remember that in order to move in other than a straight line, something must be accelerating you

The spacecraft is travelling straight to the **left,**

but it is accelerating **downwards**,

i.e. the velocity is trying to change to a downward direction

The net result is that the spacecraft does not keep travelling straight to the left, but **curves** downwards and is displaced downwards and leftwards

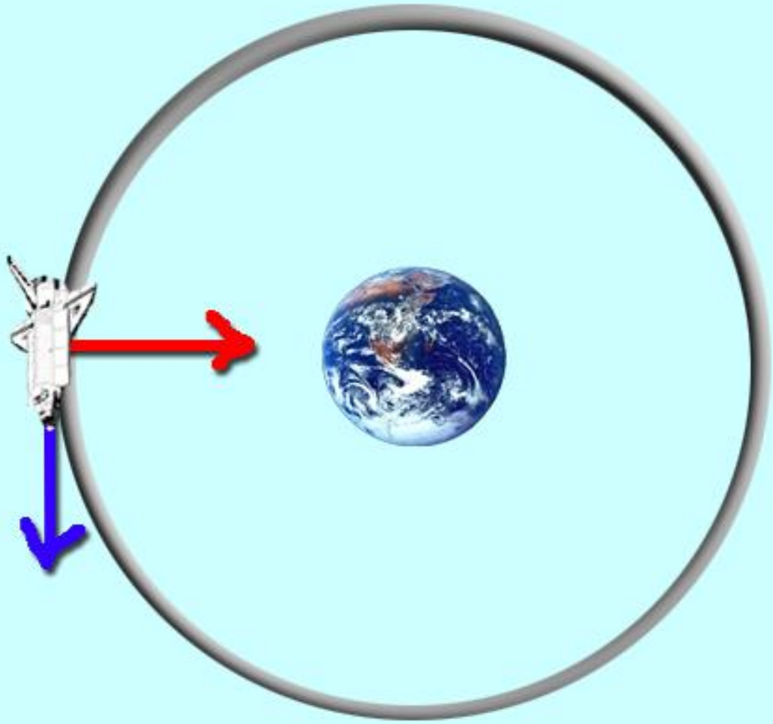


The spacecraft is travelling straight to **downwards**,

but it is accelerating to the **right**,

i.e. the velocity is trying to change to a rightward direction

The net result is that the spacecraft does not keep travelling straight downwards, but **curves** to the right and is displaced downwards and rightwards

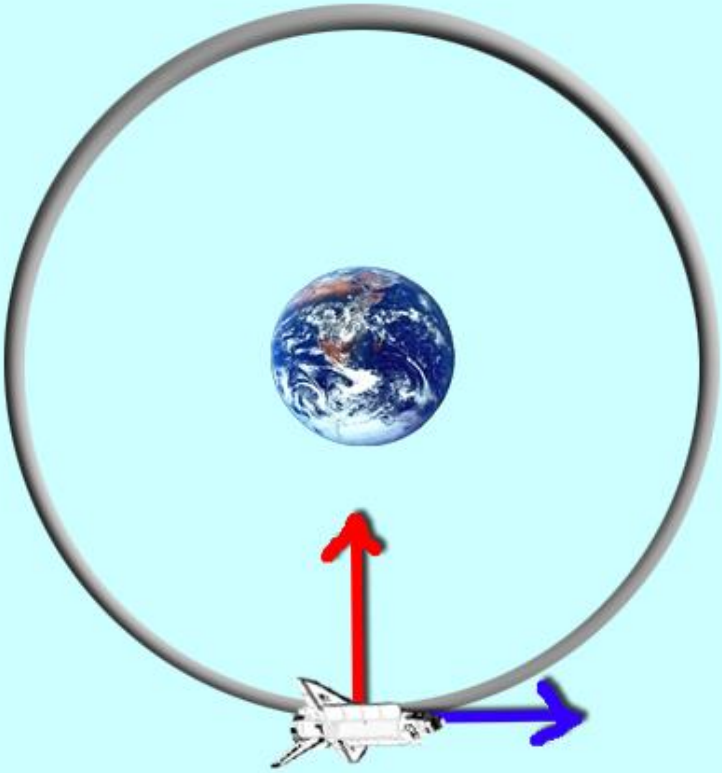


The spacecraft is travelling straight to **right**,

but it is accelerating **upwards**,

i.e. the velocity is trying to change to a upward direction

The net result is that the spacecraft does not keep travelling straight to the right, but **curves** upward and is displaced upward and rightwards

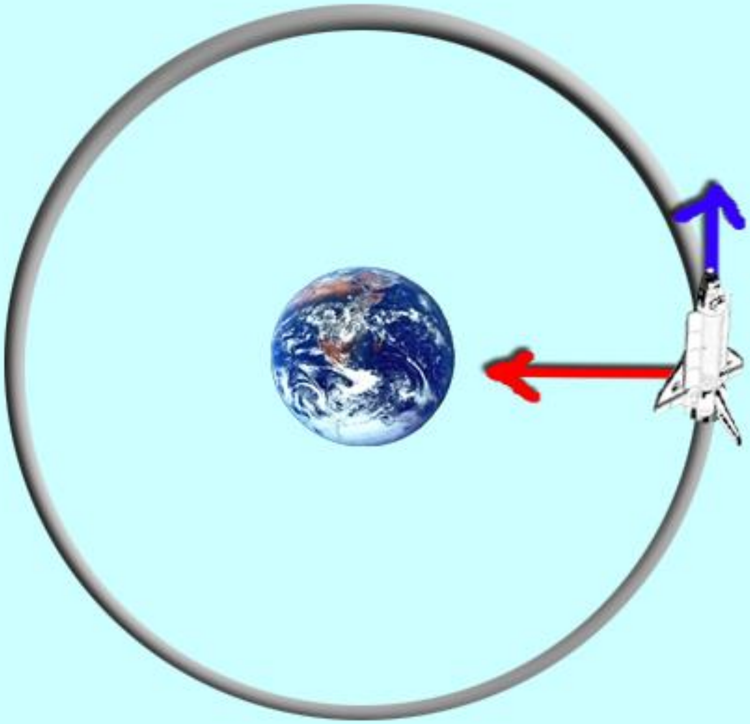


The spacecraft is travelling straight to **upwards**,

but it is accelerating to the **left**,

i.e. the velocity is trying to change to a leftward direction

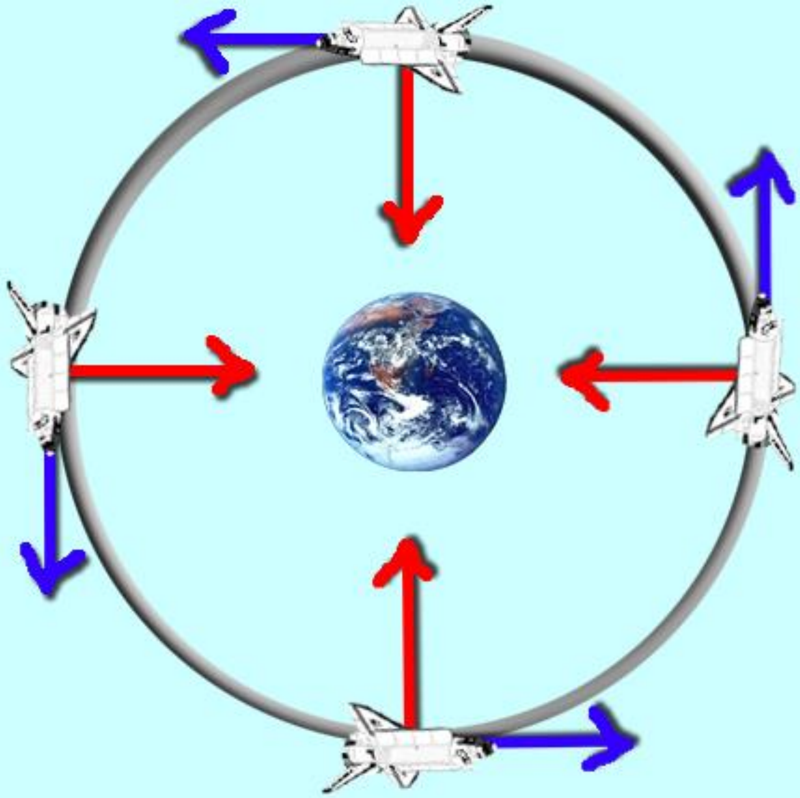
The net result is that the spacecraft does not keep travelling straight upwards, but **curves** to the left and is displaced diagonally upwards and leftwards



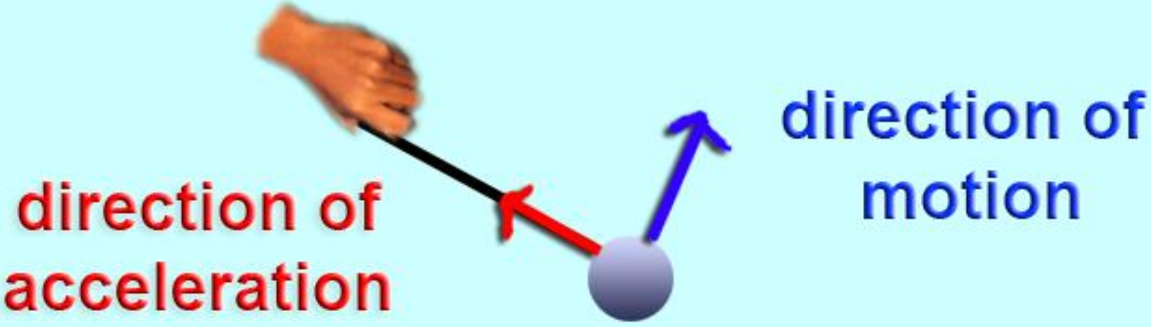
At every point in its path, the spacecraft is **accelerating** in a direction that is perpendicular (i.e. makes an angle of 90°) to the **direction of motion**, and continuously curves.

Therefore, the combined path curves and forms a circle.

Note: A circular path is generated if the acceleration has a specific magnitude based on the speed; if not, the path may be elliptical or parabolic instead of circular



looking down from the ceiling

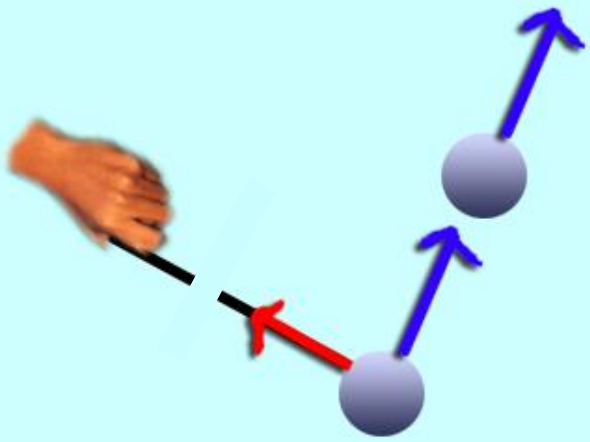


looking down from the ceiling

what would happen to the ball if the string broke?

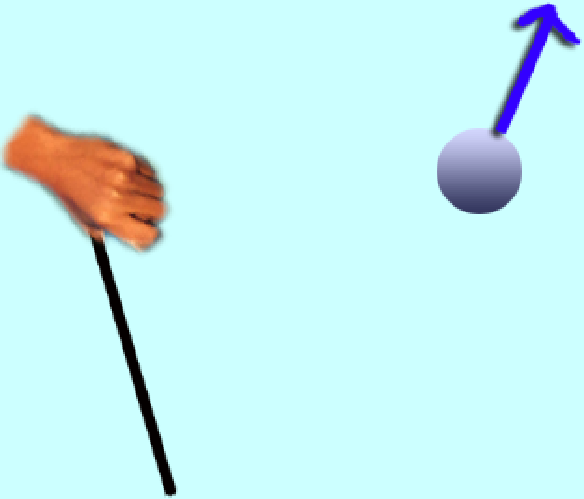
looking down from the ceiling

what would happen to the ball if the string broke?



looking down from the ceiling

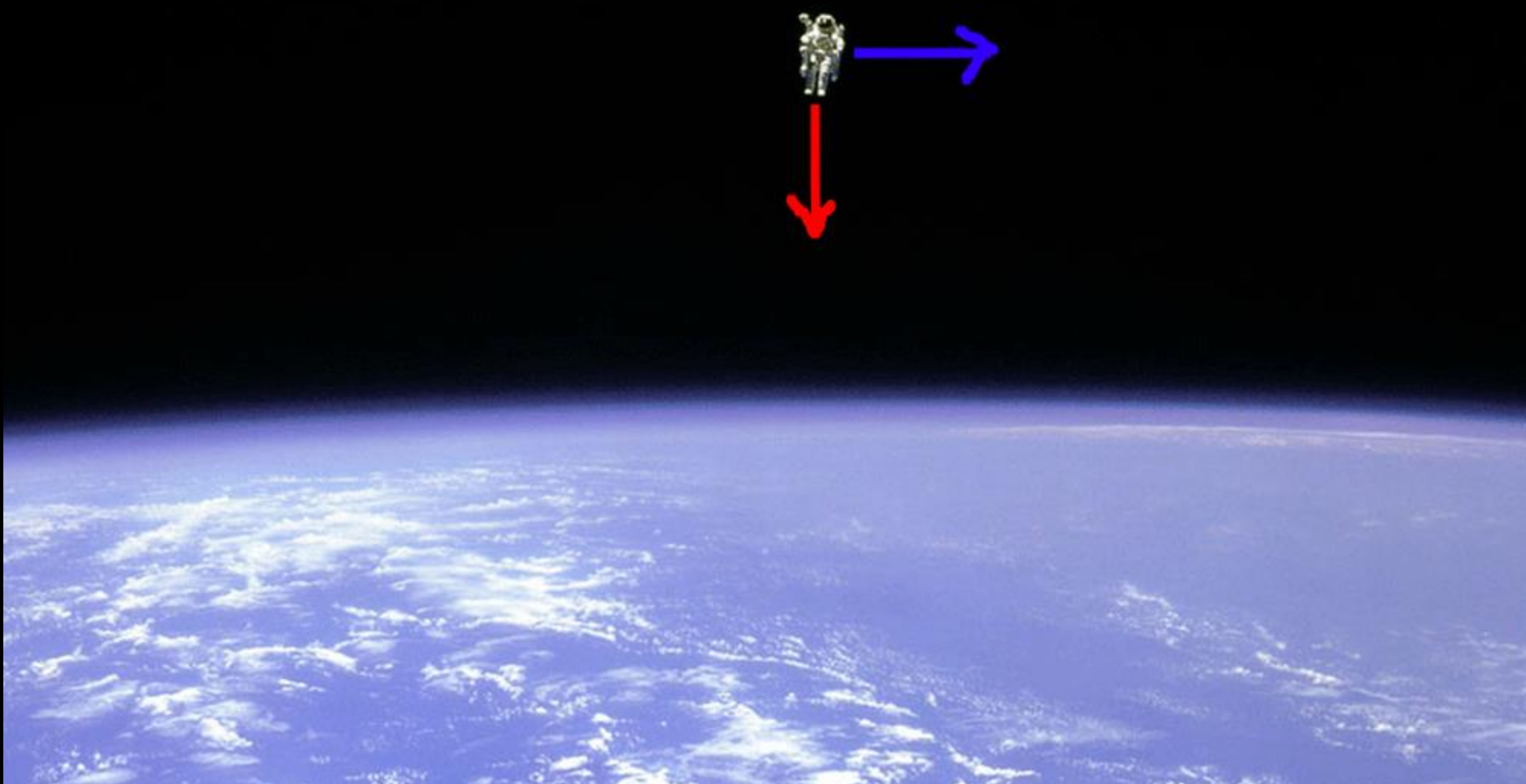
If we are looking from above so gravity is pulling the ball downward, our view of the ball would see it going straight. If our view is from the side, then the ball would make a parabolic descent to the ground



looking down from the ceiling

So what is keeping the astronaut from falling to Earth?

the acceleration of Gravity
turns the astronaut as his horizontal speed
makes him miss the ground.



As gravity pulls him down, his speed moves him sideways. Gravity can only pull downward.

So the astronaut is in free fall around the Earth

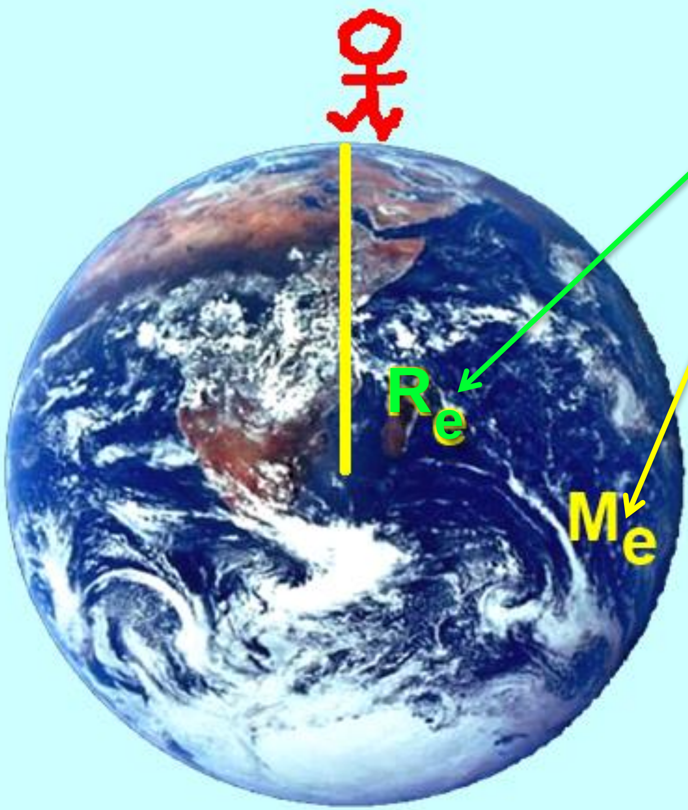
$V_{orbit} = 5\ mi/s$

mass depends only on the total amount of stuff that makes you up

weight depends on the MASS and SIZE of the planet you're standing on unit of MASS is a kilogram (kg)

unit of WEIGHT is a Newton (N) (metric)
or a pound (lb) (American)

$$Wt_{\text{you on earth}} = F_{grav} = \frac{M_e \, m_{you} \, G}{R_e^2}$$



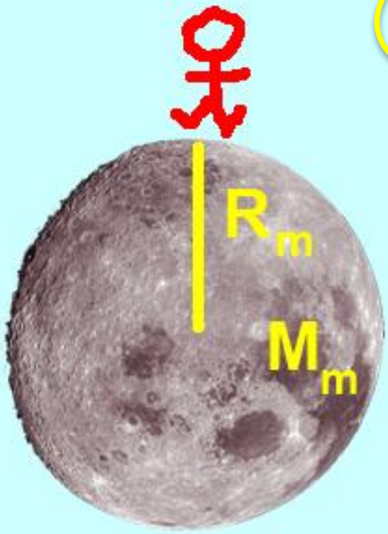
the more COMPACT the planet, the more you weigh

$$Wt_{\text{you on earth}} = F_{grav} = \frac{M_e \, m_{you} \, G}{R_e^2}$$

$$Wt_m = \frac{M_m \, m_{you} \, G}{R_m^2}$$

$$Wt_{\substack{you\\on\\earth}} = F_{grav} = \frac{M_e\, m_{you}\, G}{R_e^2}$$

$$M_m = \frac{1}{100} M_e$$

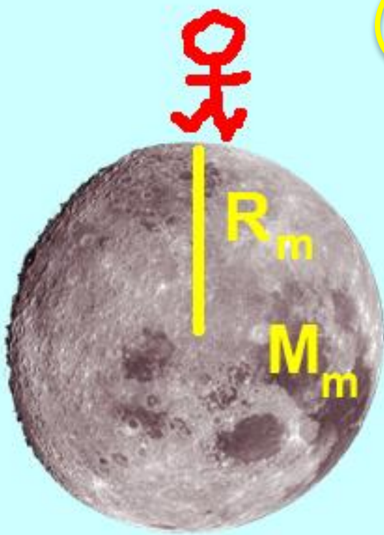


$$Wt_m = \frac{M_m\, m_{you}\, G}{R_m^2}$$

$$Wt_{\text{you on earth}} = F_{grav} = \frac{M_e \, m_{you} \, G}{R_e^2}$$

$$M_m = \frac{1}{100} M_e$$

$$R_m = \frac{1}{4} R_e$$



$$Wt_m = \frac{M_m \, m_{you} \, G}{R_m^2}$$

$$Wt_{\substack{you\\on\\earth}} = F_{grav} = \frac{M_e\, m_{you}\, G}{R_e^2}$$

$$M_m = \frac{1}{100} M_e$$

$$R_m = \frac{1}{4} R_e$$

$$Wt_m = \frac{\frac{1}{100} M_e\, m_{you}\, G}{\left(\frac{1}{4} R_e\right)^2}$$

$$Wt_{\substack{you\\on\\earth}} = F_{grav} = \frac{M_e\, m_{you}\, G}{R_e^2}$$

$$M_m = \frac{1}{100} M_e$$

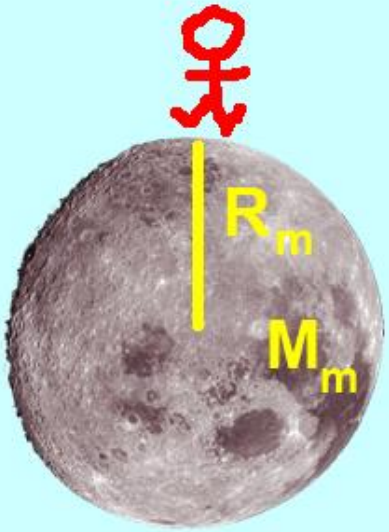
$$R_m = \frac{1}{4} R_e$$

$$Wt_m = \frac{\frac{1}{100} M_e\, m_{you}\, G}{\frac{1}{16} R_e^2}$$

$$Wt_{\substack{you\\on\\earth}} = F_{grav} = \frac{M_e\, m_{you}\, G}{R_e^2}$$

$$M_m = \frac{1}{100} M_e$$

$$R_m = \frac{1}{4} R_e$$

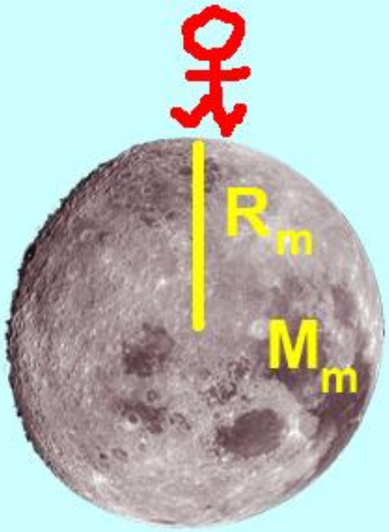


$$Wt_m = \frac{16\, M_e\, m_{you}\, G}{100\quad R_e^2}$$

$$Wt_{\substack{you\\ on\\ earth}} = F_{grav} = \frac{M_e m_{you} G}{R_e^2}$$

$$M_m = \frac{1}{100} M_e$$

$$R_m = \frac{1}{4} R_e$$



$$Wt_m = \frac{16}{100} \times \frac{M_e m_{you} G}{R_e^2}$$

$$Wt_{\substack{you \\ on \\ earth}} = F_{grav} = \frac{M_e \, m_{you} \, G}{R_e^2}$$

$$M_m = \frac{1}{100} M_e$$

$$R_m = \frac{1}{4} R_e$$

$$Wt_m = \frac{16}{100} \times \frac{M_e \, m_{you} \, G}{R_e^2}$$

$$Wt_{\substack{you \\ on \\ earth}} = F_{grav} = \frac{M_e\, m_{you}\, G}{R_e^2}$$

$$M_m = \frac{1}{100} M_e$$

$$R_m = \frac{1}{4} R_e$$

$$Wt_m = \frac{16}{100} \times Wt_{\substack{you \\ on \\ earth}}$$

$$Wt_{\substack{you\\on\\earth}} = F_{grav} = \frac{M_e\, m_{you}\, G}{R_e}$$

$$M_m = \frac{1}{100} M_e$$

$$R_m = \frac{1}{4} R_e$$

$$Wt_m = \frac{16\, M_e\, m_{you}\, G}{100 \quad R_e^2}$$

$$Wt_m = \frac{16}{100} \times Wt_{\substack{you\\on\\earth}}$$

$$Wt_{\substack{you\\on\\earth}} = F_{grav} = \frac{M_e\, m_{you}\, G}{R_e}$$

$$M_m = \frac{1}{100} M_e$$

$$R_m = \frac{1}{4} R_e$$

$$Wt_m = \frac{16\, M_e\, m_{you}\, G}{100\ \ R_e^2}$$

$$Wt_m \approx \frac{1}{6}\, Wt_{\substack{you\\on\\earth}}$$

$$Wt_m \simeq \frac{1}{6}\, Wt_{\text{you on earth}}$$

If you weigh 120 lbs on Earth, what would you weigh on the Moon?

Let's consider the acceleration of gravity near Earth's surface

a = 32 (ft per sec) per sec

As you fall, your speed will increase by 32 ft/s every second you're in flight toward the ground

Let's consider the acceleration of gravity near Earth's surface

a = 32 (ft per sec) per sec

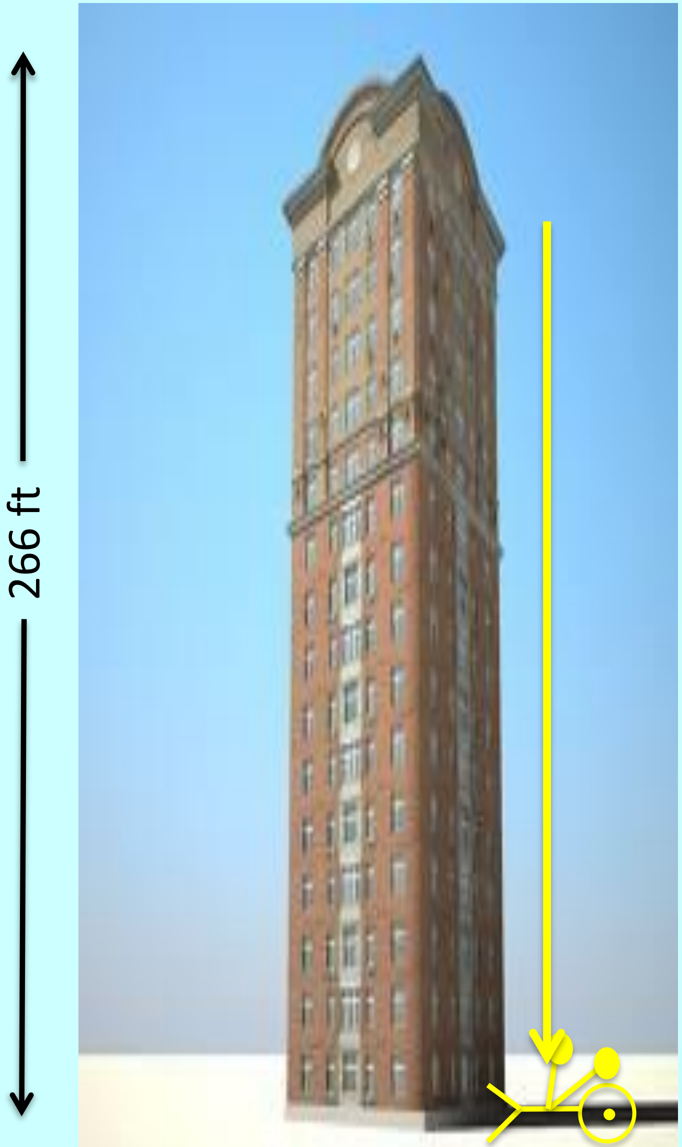
So the higher you fall, the faster you'll be going when you hit the ground

Let's consider the acceleration of gravity near Earth's surface

a = 32 (ft per sec) per sec

after 1 sec, v = 32 ft/s

Let's consider the acceleration of gravity near Earth's surface



a = 32 (ft per sec) per sec

after 1 sec, v = 32 ft/s

after 2 sec, v = 64 ft/s

after 3 sec, v = 96 ft/s

after 4 sec, v = 128 ft/s — SPLAT

Let's consider the acceleration of gravity near Earth's surface

a = 32 (ft per sec) per sec

If the building had been taller, you would have hit the ground going even faster —> BIGGER SPLAT

Let's say you weigh 120 lbs.

If you and a ball of iron weighing 500 lbs fell off at the same time,

You'd both hit the ground at the same time! Everything falls at the same rate.

Let's say you weigh 120 lbs.

If you and a ball of iron weighing 500 lbs fell off at the same time,

You'd both hit the ground at the same time! Everything falls at the same rate.

The speed at impact would be $v = 128$ ft/s for both

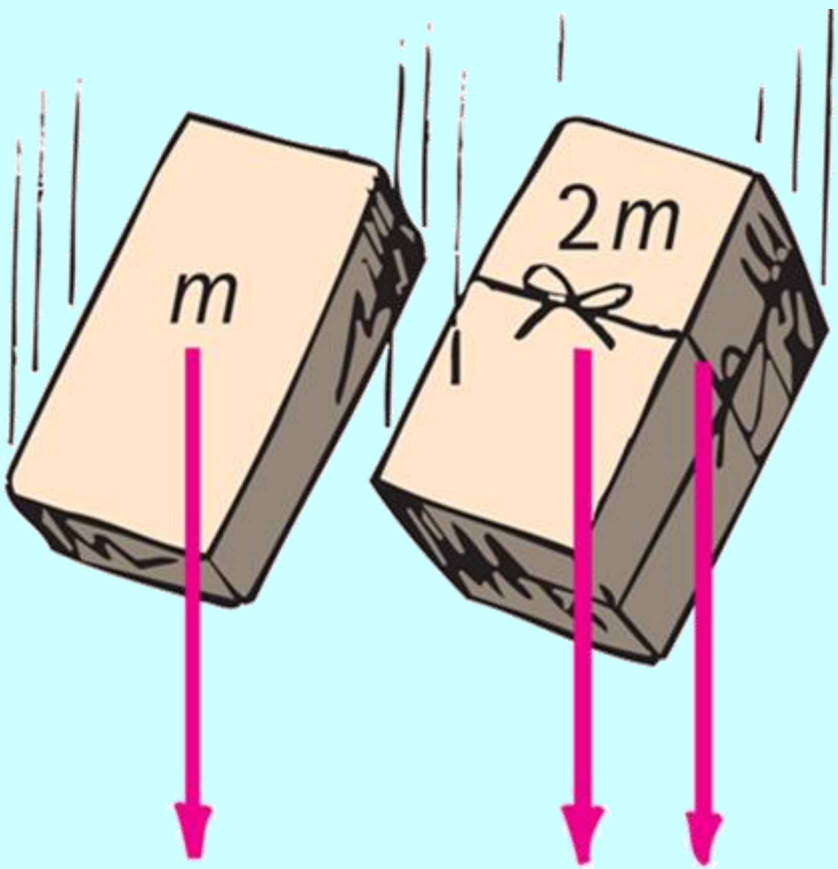
Let's say you weigh 120 lbs.

If you and a ball of iron weighing 500 lbs fell off at the same time,

Who would hit the ground with the greater force?

The speed at impact would be v = 128 ft/s for both

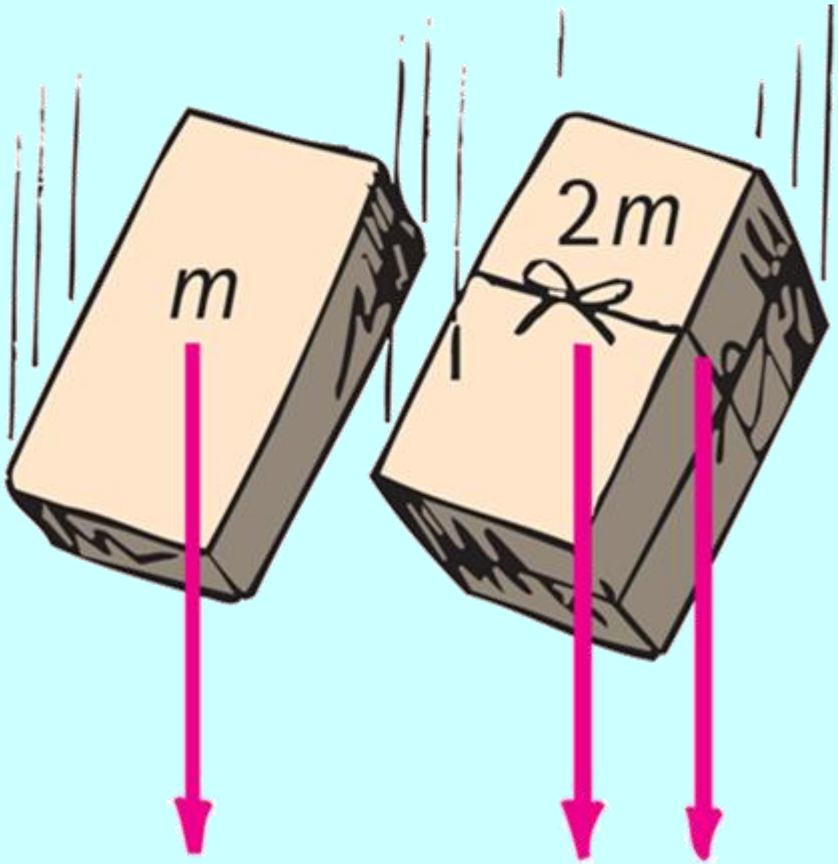
Why do things at the same height fall at the same rate?



fall rate =

a = $32\ ft/s^2$

In other words, why is their acceleration independent of their mass?



$$F_{\text{on mass m}} = \frac{m\ M_e G}{R_e^2} = m\ a$$

$$F_{\text{on mass m}} = \frac{m\,M_e G}{R_e^2} = m\,a$$

$$F_{\text{on mass m}} = \frac{m\,M_e G}{R_e^2} = m\,a$$

$$\frac{\cancel{m}\,M_e G}{R_e^2} = \cancel{m}\,a$$

$$F_{\text{on mass m}} = \frac{m\,M_e G}{R_e^2} = m\,a$$

$$\frac{m\,M_e G}{R_e^2} = m\,a$$

$$\frac{M_e G}{R_e^2} = a$$

$$F_{\text{on mass } m} = \frac{m\,M_e G}{R_e^2} = m\,a$$

$$\frac{m\,M_e G}{R_e^2} = m\,a$$

$$\boxed{\frac{M_e G}{R_e^2} = a}$$

fall rate is independent of mass, m!

$$F_{\text{on mass } m} = \frac{m\, M_e G}{R_e^2} = m\, a$$

$$\frac{m\, M_e G}{R_e^2} = m\, a$$

$$\boxed{\frac{M_e G}{R_e^2} = a} = g$$

Let's calculate the value of a

$$a = \frac{M_e G}{R_e^2} = g$$

$$a = \frac{(6 \times 10^{24}\ \text{kg}) \times (6.67 \times 10^{-11}\ \text{m}^3/\text{kg/ s}^2)}{(6.374 \times 10^{6}\ \text{m})^2} = g$$

$$a = 9.8\ \text{m/s}^2 = 32\ \text{ft/s}^2 = g$$

acceleration due to gravity near Earth's surface

$$F_{\text{on mass } m} = \frac{m\, M_e G}{R_e^2} = m\, a$$

$$a = \frac{M_e G}{R_e^2} = 32\ \frac{\text{ft/s}}{\text{s}}$$

So, the acceleration of an object falling to Earth is independent of its mass! From a given height above Earth, all things fall at the same rate!!

We live in an Air Force community and pilots talk about pulling so many g's in their planes.

What are they talking about?

When you are standing on the ground, you feel your weight — 1 g

We live in an Air Force community and pilots talk about pulling so many g's in their planes.

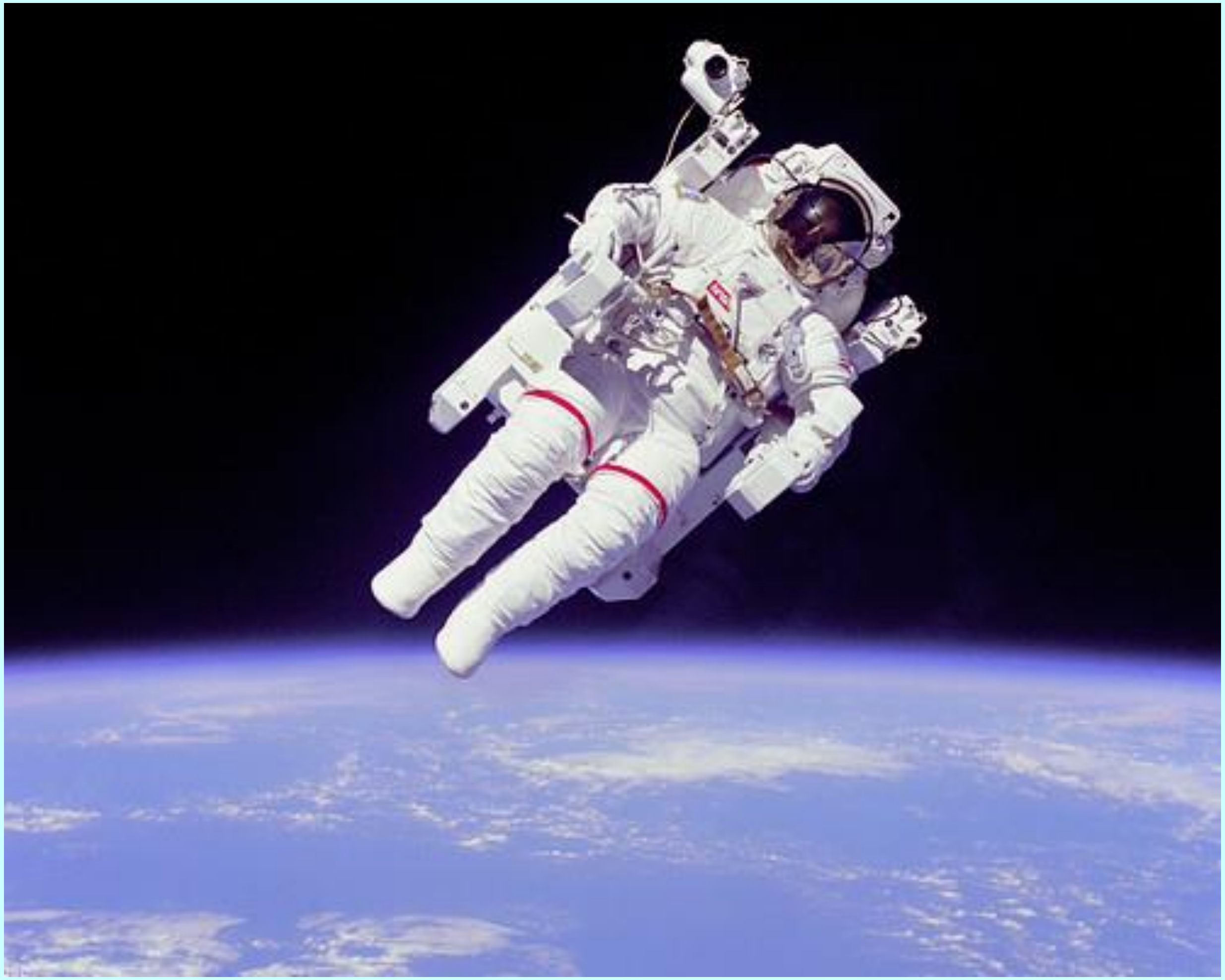
What are they talking about?

When you take off, you feel the acceleration of the engines against Earth's gravity — 2.5 g or larger

This pilot feels 2.5 times his weight

In Free-Fall you do not feel your weight

In free fall (ex., in orbit or falling from a building) you experience 0 g



A car accelerating from 0 to 100 mph in 10 seconds is 0.28 g

(get shoved back in your seat by about ¼ your weight)

Taking off in an airplane 1.5 g

(get shoved back in your seat by 1.5 times your weight)

Wicked Roller Coaster

4.3 g

Apollo re-entry to Earth
7.19 g

Human Body can take about 13 g, but not for long.

This puts a strict limit on how fast we can accelerate space ships for interstellar travel.

Let's go back to the big SPLAT.

Would you and the 500 lb iron ball hit the ground with the same FORCE?

Your speeds at impact would both be v = 128 ft/s

Let's calculate.

$$F_{\substack{\text{of you}\\ \text{on earth}}} = m_{\text{you}}\ a$$

$$F_{\substack{\text{of ball}\\ \text{on earth}}} = M_{\text{ball}}\ a$$

$$\text{acceleration} = \frac{\text{change in velocity when you hit the ground}}{\text{how long it takes to stop}}$$

Let's calculate.

$$F_{\text{of you on earth}} = m_{you} \frac{(128 \text{ ft/s} - 0 \text{ ft/s})}{1/10 \text{ s}}$$

$$F_{\text{of ball on earth}} = M_{ball} \frac{(128 \text{ ft/s} - 0 \text{ ft/s})}{1/10 \text{ s}}$$

change in velocity when
you hit the ground

Let's calculate.

$$F_{\text{of you on earth}} = m_{you} \frac{(128\ ft/s - 0\ ft/s)}{1/10\ s}$$

$$F_{\text{of ball on earth}} = M_{ball} \frac{(128\ ft/s - 0\ ft/s)}{1/10\ s}$$

how long it takes you
to come to a stop

Let's calculate.

$$F_{\substack{\text{of you}\\ \text{on earth}}} = m_{you} \frac{(128\ \text{ft/s} - 0\ \text{ft/s})}{1/10\ \text{s}}$$

$$F_{\substack{\text{of ball}\\ \text{on earth}}} = M_{ball} \frac{(128\ \text{ft/s} - 0\ \text{ft/s})}{1/10\ \text{s}}$$

$F_{\text{of you}} =$ 5,060 lb

$F_{\text{of ball}} =$ 21,120 lb

Why do stuntmen survive?

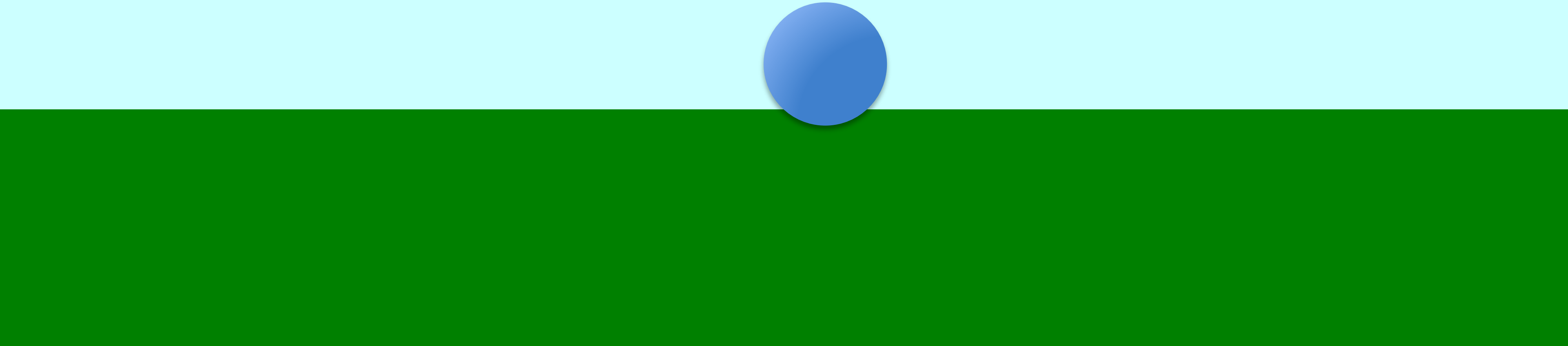
$$F_{\text{of you on earth}} = m_{you}\,\frac{(128\ \text{ft/s} - 0\ \text{ft/s})}{2\ \text{s}}$$

$$F_{\text{of you}} = 253\ \text{lb}$$

this slows the stop — acceleration smaller

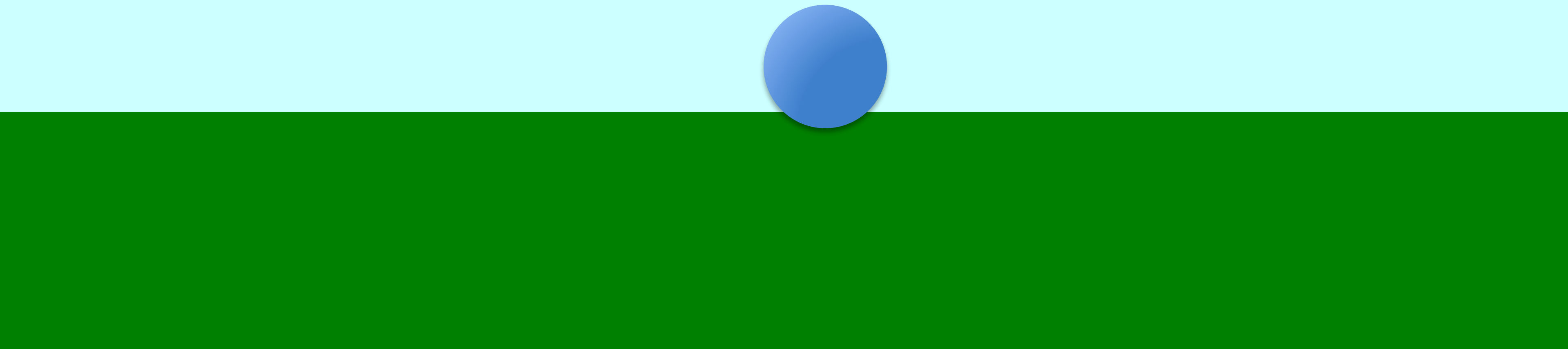
If you toss a ball up…

It will come back down.



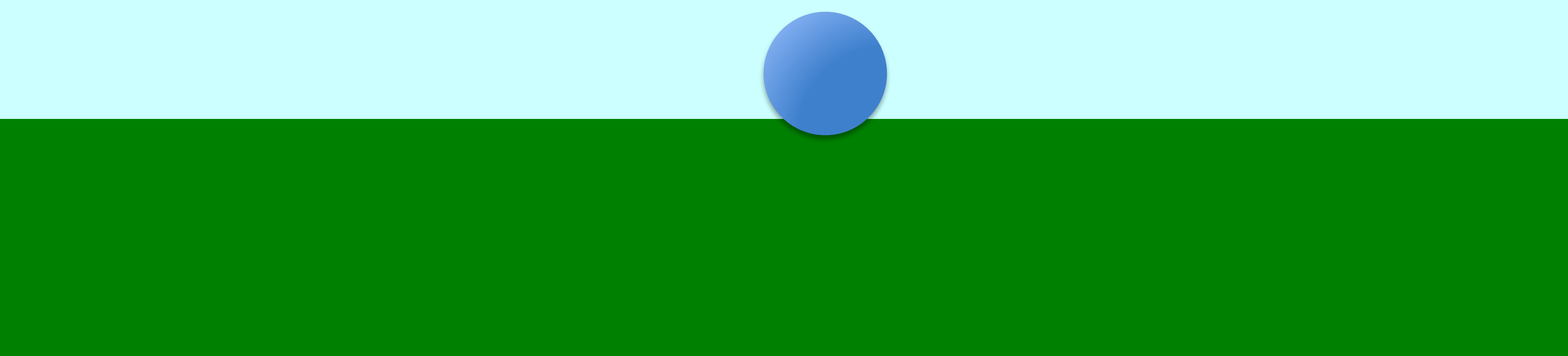
If you toss it faster it will go higher…

but it will come back down.



If you throw it at the ESCAPE SPEED of Earth….

it will NEVER come back down.



This is escape speed. It depends on the **mass** and **size** of the **planet** you want to escape, in this case, Earth.

The escape speed of Earth is 7 mi/s = 25,200 mph.

$$v_{esc} = \sqrt{\frac{2GM_P}{R_P}}$$

What is the fundamental difference between this and the gravity equation?

$$F_P = \frac{mM_pG}{R_p^2}$$

$$v_{esc} = \sqrt{\frac{2GM_P}{R_P}}$$

Note that the mass of the object trying to leave the planet is not in the V_{esc} equation!

$$F_P = \frac{mM_pG}{R_p^2}$$

$$v_{esc_{earth}} = \sqrt{\frac{2GM_{earth}}{R_{earth}}}$$

A rocket or a baseball both need to reach 7 mi/s in order to escape Earth.

25,200 mph !!

$$v_{esc\ moon} = \sqrt{\frac{2GM_{moon}}{R_{moon}}}$$

What about escaping the Moon?

$$v_{esc\ moon} = \sqrt{\frac{2GM_{moon}}{R_{moon}}}$$

$$M_{moon} = \frac{1}{100} M_{earth}$$

$$R_{moon} = \frac{1}{4} R_{earth}$$

$$v_{esc\ moon} = \sqrt{\frac{2GM_{moon}}{R_{moon}}}$$

put those numbers into the equation and:

$$v_{esc\ moon} = \sqrt{\frac{2G\left(\frac{1}{100}M_{earth}\right)}{\left(\frac{1}{4}R_{earth}\right)}}$$

$$v_{esc\ earth} = \sqrt{\frac{2GM_{earth}}{R_{earth}}}$$

compare with escape speed from earth:

$$v_{esc\ moon} = \sqrt{\frac{\frac{1}{100}\,2GM_{earth}}{\frac{1}{4}\,R_{earth}}}$$

$$v_{esc\ earth} = \sqrt{\frac{2GM_{earth}}{R_{earth}}}$$

compare with escape speed from earth:

$$v_{esc\ moon} = \sqrt{\frac{\frac{1}{100}2GM_{earth}}{\frac{1}{4}R_{earth}}}$$

$$v_{esc\ earth} = \sqrt{\frac{2GM_{earth}}{R_{earth}}}$$

which is:

$$v_{esc\ moon} = \sqrt{\frac{4}{100}}\sqrt{\frac{2GM_{earth}}{R_{earth}}}$$

$$v_{esc\ earth} = \sqrt{\frac{2GM_{earth}}{R_{earth}}}$$

which is:

$$v_{esc\ moon} = \sqrt{\frac{4}{100}} \times v_{esc\ earth}$$

$$v_{esc\ earth} = \sqrt{\frac{2GM_{earth}}{R_{earth}}}$$

which is:

$$v_{esc\ moon} = \sqrt{\frac{1}{25}} \times v_{esc\ earth}$$

$$v_{esc\ earth} = \sqrt{\frac{2GM_{earth}}{R_{earth}}}$$

which is:

$$v_{esc\ moon} = \frac{1}{5} \times v_{esc\ earth}$$

$$v_{esc\ moon} = \frac{1}{5} \times v_{esc\ earth}$$

$$v_{esc\ moon} = 1.4 \text{ mi/s} = 5{,}040 \text{ mph}$$

The more compact the planet, the more you weigh and the faster you must go to escape. The fluffier the planet, the less you weigh and the slower you can go to escape.