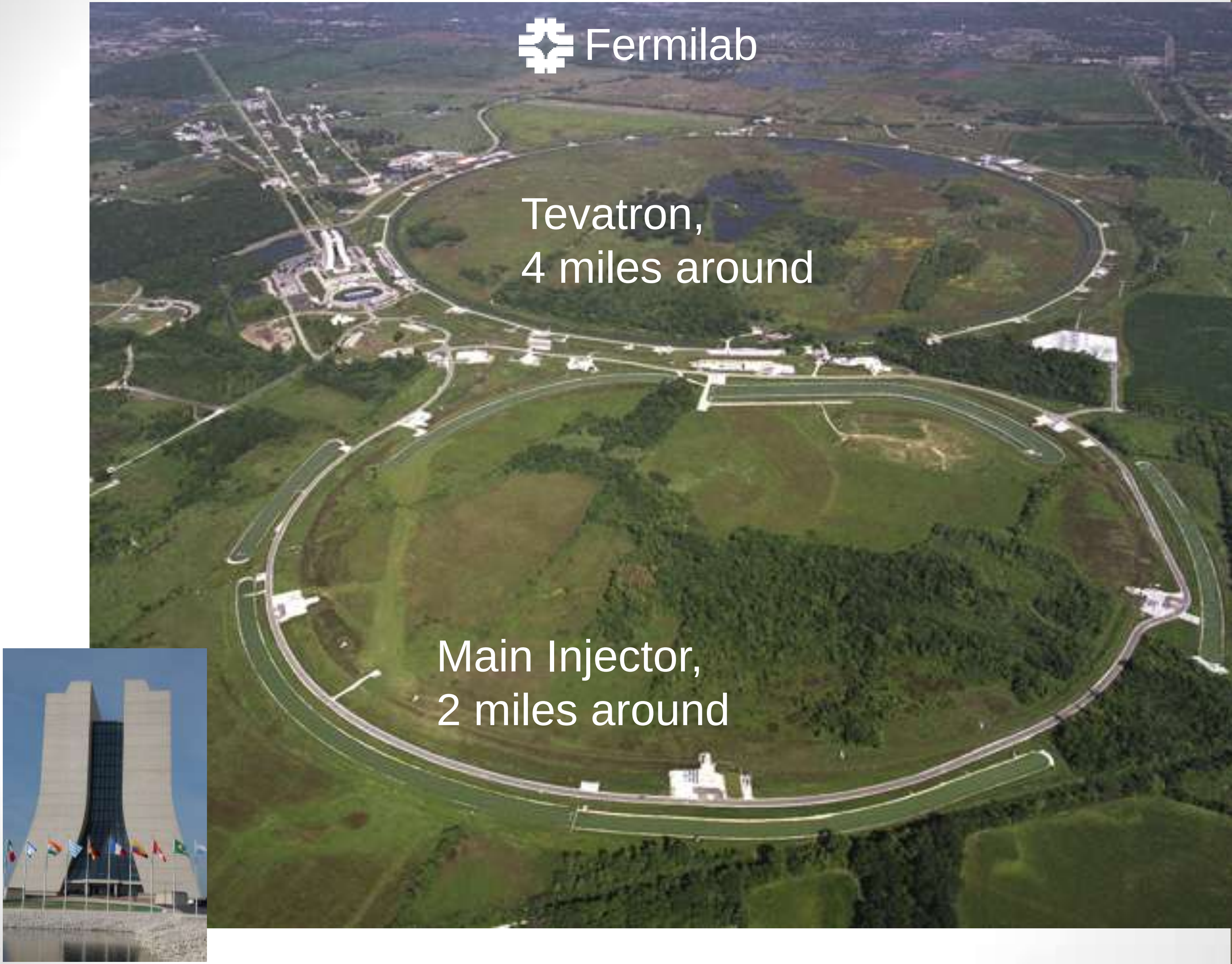
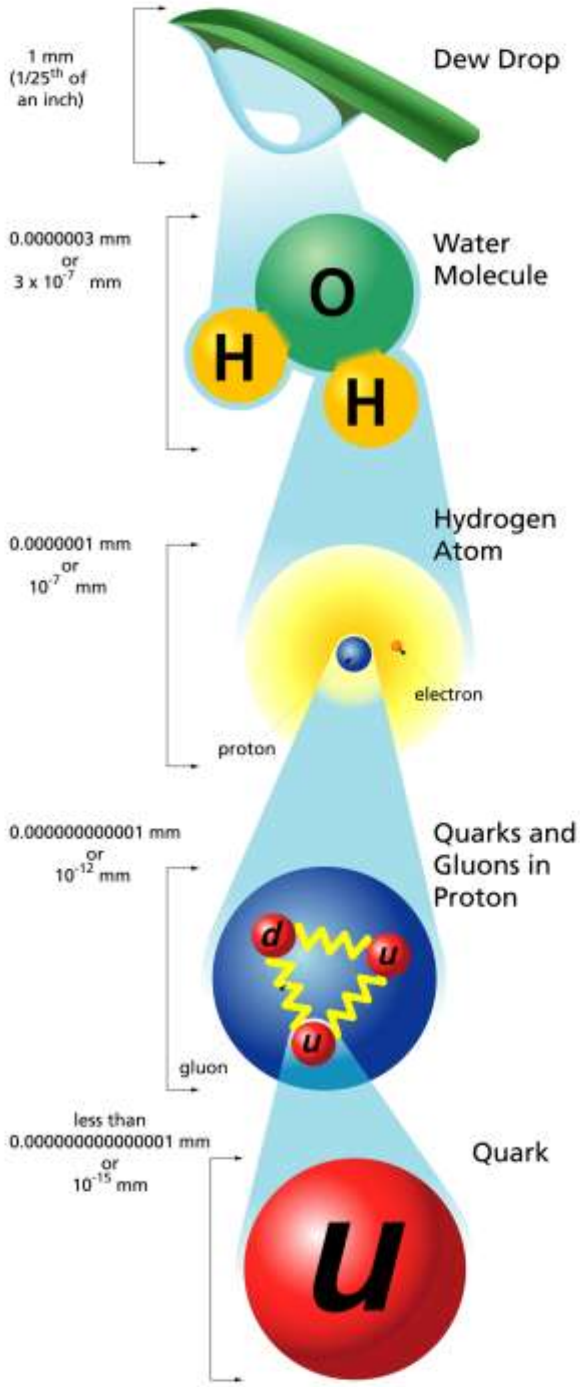
Forces and Motion


Fermilab
Tevatron,
4 miles around
Main Injector,
2 miles around

Physics explains things that are very, very large.

Physics explains things that are very, very small.



Physics explains things that are right in front of us.

Newton’s First Law

- Objects at rest remain at rest
- Objects in motion remain in motion

UNTIL YOU APPLY A FORCE

Objects tend to resist a change in motion. This is called:

Inertia

Newton’s Second Law

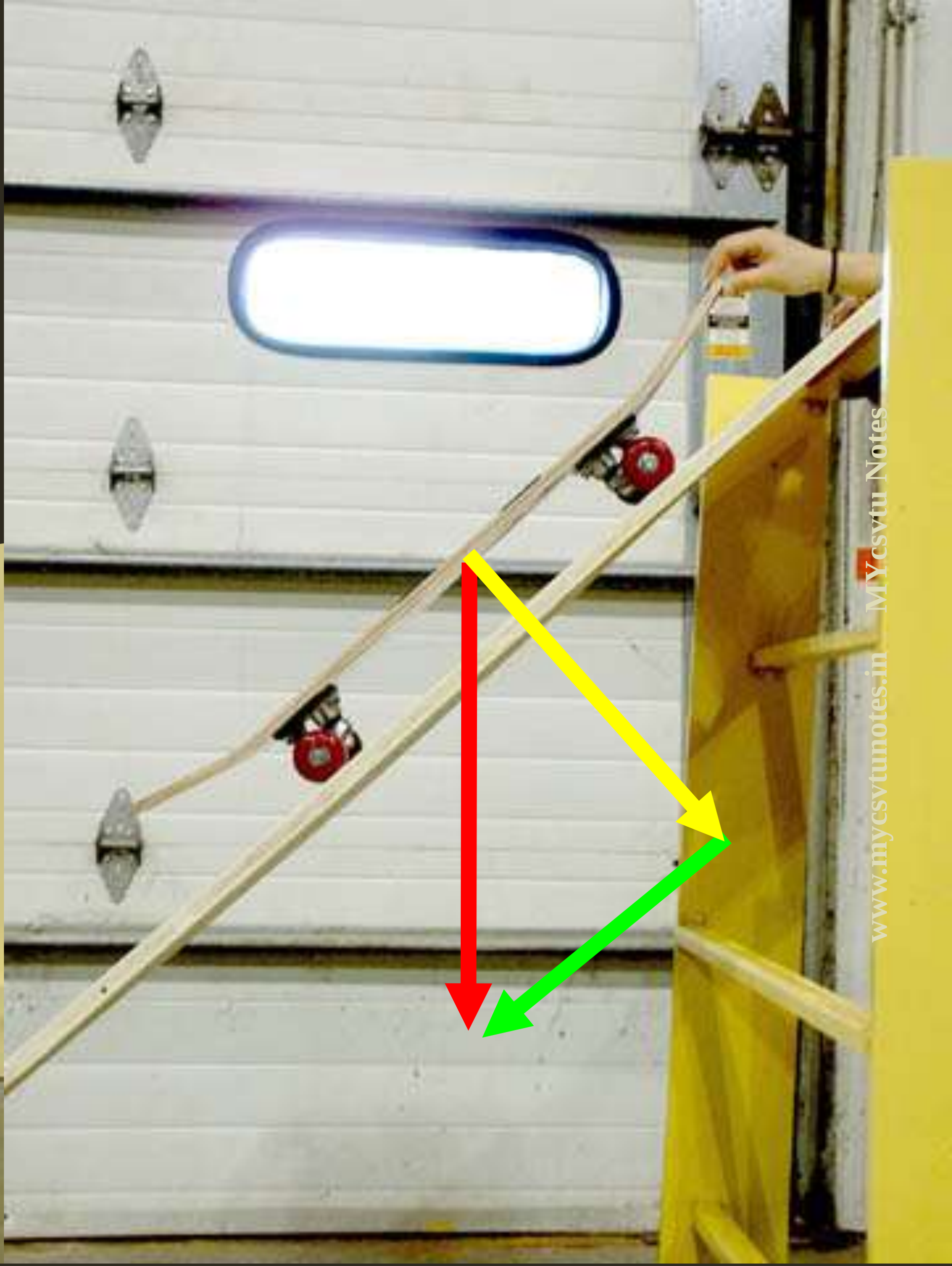
F = ma

What is a force?

Weight due to gravity (down)

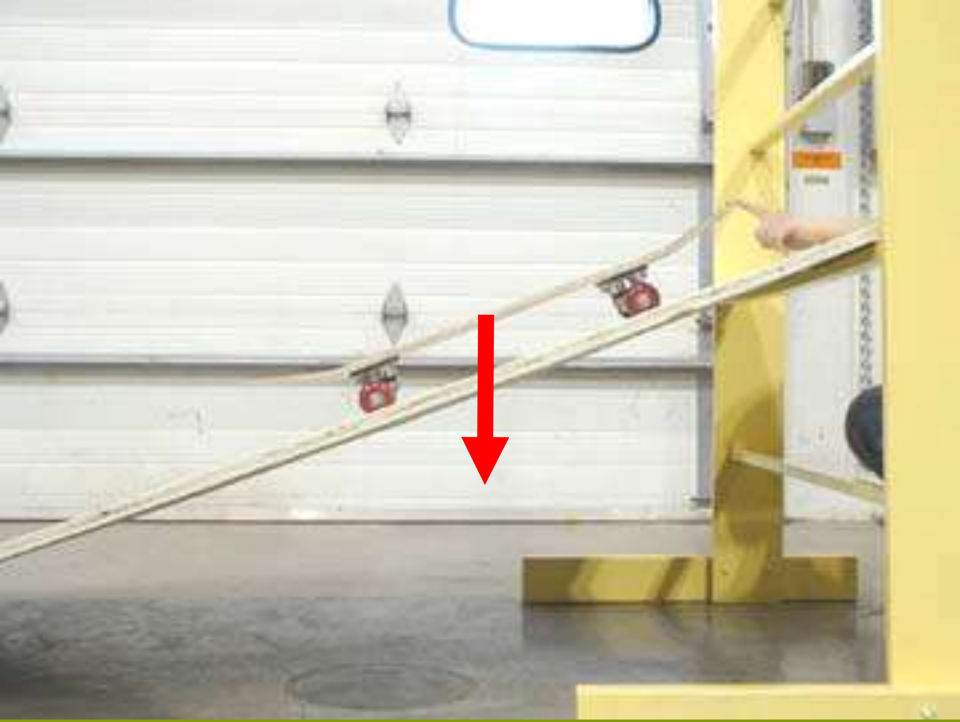
Amount of weight keeping board on ramp

Amount of weight making board move down ramp



Although weight doesn't change, the amount making the skateboard move does


Boards hit bottom at same time



Weight (force) goes up, but so does mass (inertia).

The two cancel out, so the two skateboards move at the same rate.

What do we expect to see with rings of the same size ?


Rings of the same size
move at the same rate

Do the shapes matter?

Rods roll **faster** than rings

Rings of the same size move at the same rate

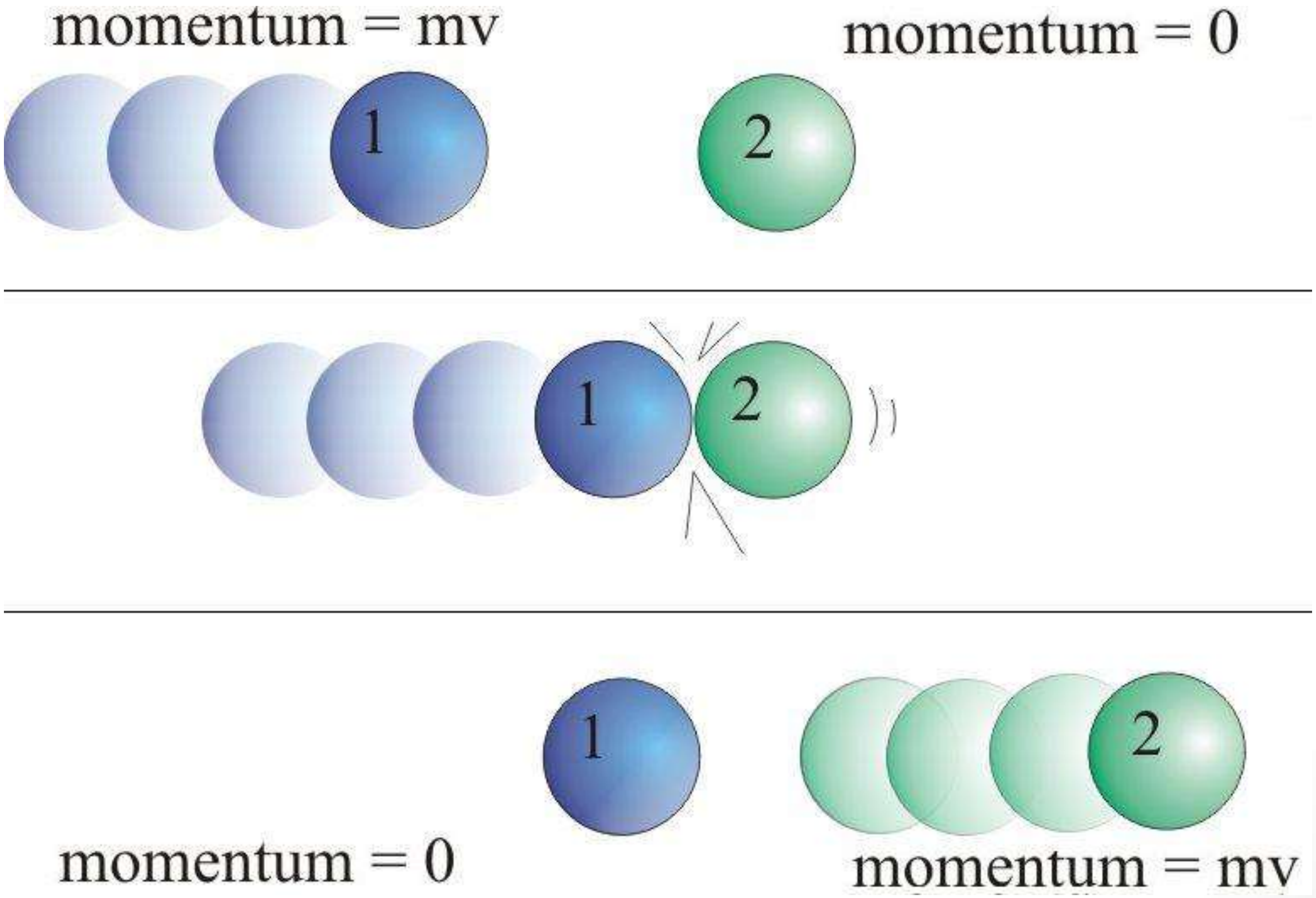
Rods roll faster than rings

In rolling cases, mass doesn't matter.
Shape does.

Newton’s Third Law

For every action there is an equal and opposite reaction.

Conservation of Momentum



If $m_1 = m_2$, then $v_1 = v_2$

Conservation of Energy

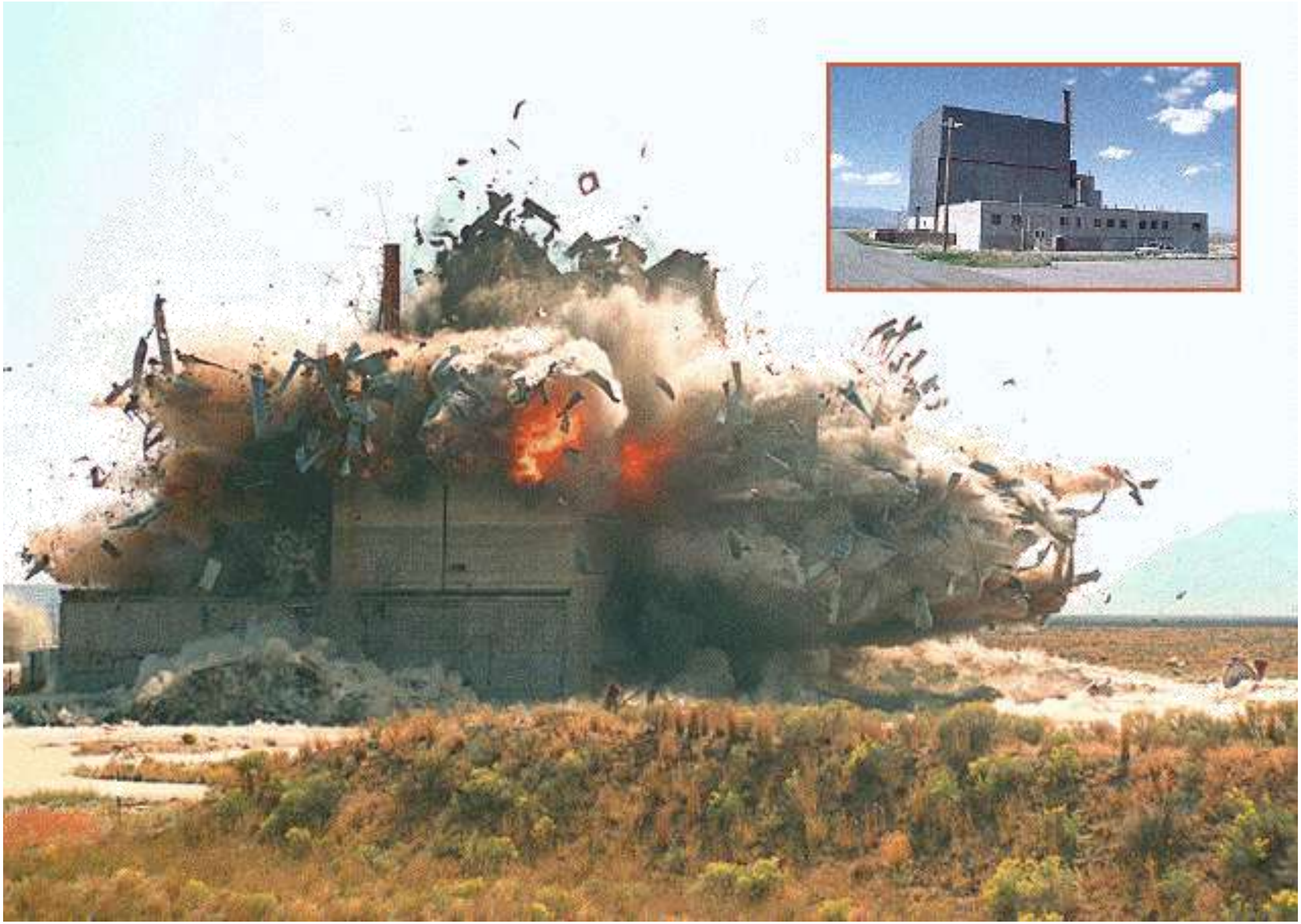
Potential Energy

Kinetic Energy

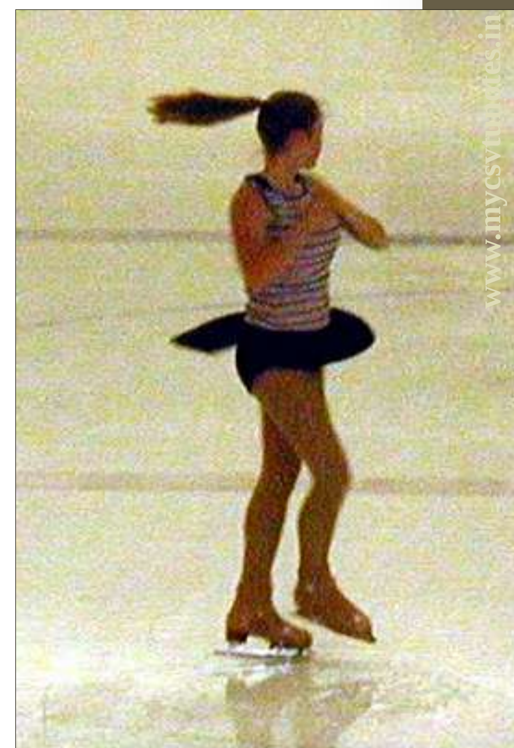
Kinetic Energy

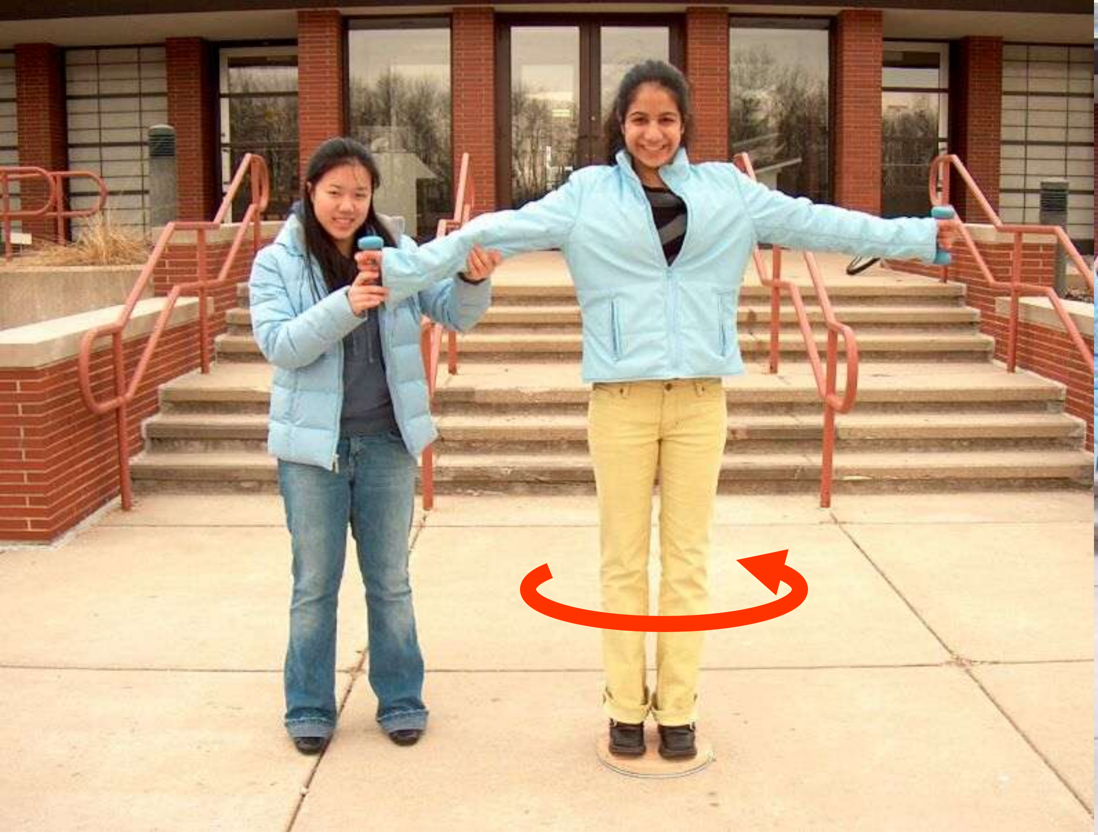
Compression Energy

Heat and Sound Energy



Spins in Figure Skating





Objects with weight far from the rotation axis spin more slowly than ones that are compact.

Things to Remember

- Inertia
  - Moving things stay moving, stationary things stay stationary
- All objects moved by gravity accelerate the same
- Rotating objects act funny
- Some things don't change and that's very useful.

Gravitation

What was so clever
about Newton's contribution?

Amongst other things, Kepler had deduced that:-

1 Planets go around the Sun in ellipses

2 The periods of their orbits (planetary years) were related to the radii of their orbits.

$$T^2 \alpha r^3$$

Newton attempted to fit these observations to ideas about gravity.

Facts available to Newton

1 Earth's circumference, originally estimated by Eratosthenes (about 200BCE) from shadow lengths, and improved by French surveyors during Newton's lifetime.

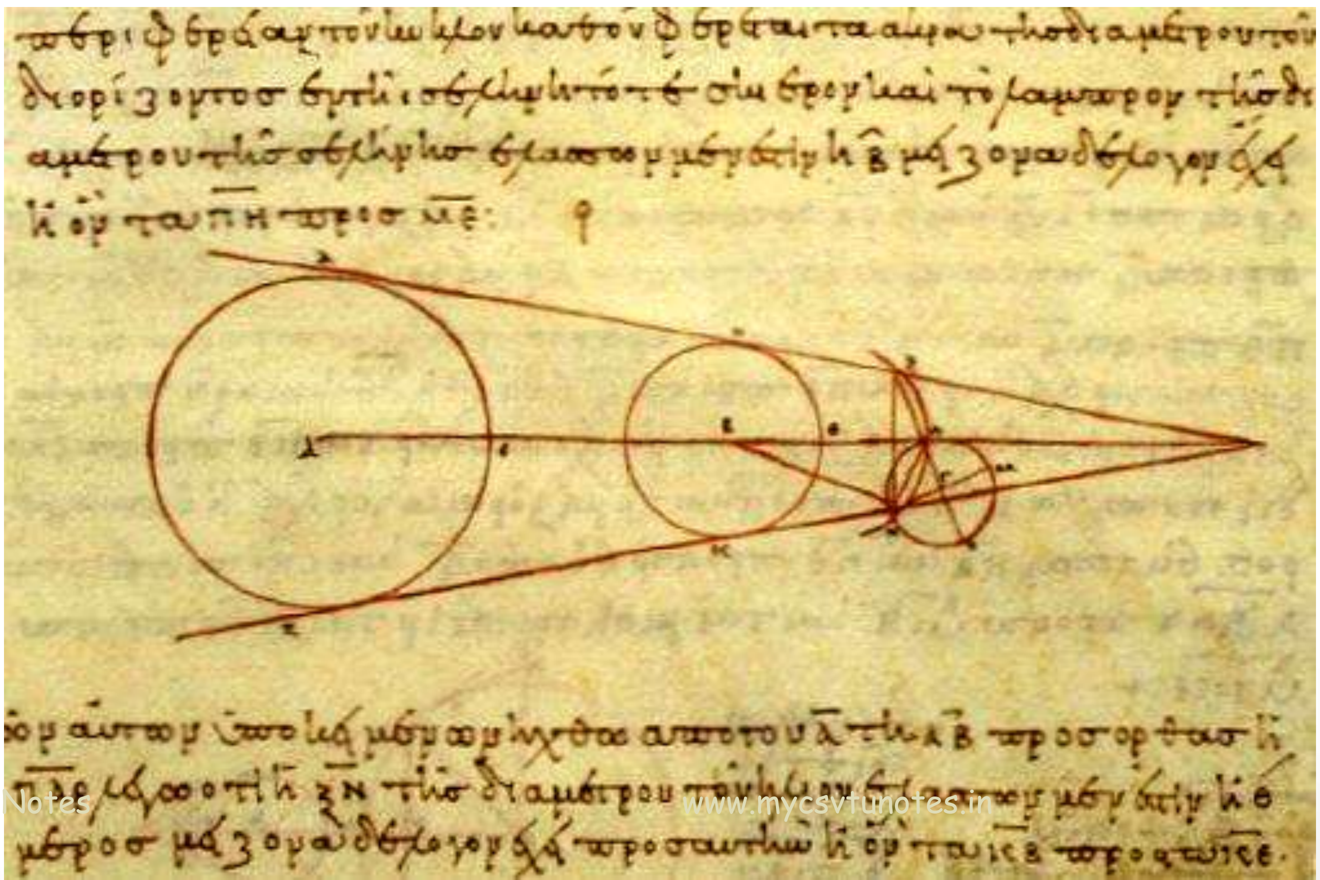
Their best value, in today's units, 69.2miles/degree = 69.2 x 360 miles

= 24900miles = 40 100km.

This implies a radius (R_e) of 6380km.

Using the size of the shadows during a lunar eclipse, they found the Moon's distance, R_{mo} to be about 60 x Earth's radius, $60R_e$.

i.e. about 60 x 6380 = 383 000km = 3.83×10^8m or 250 000miles



Fact 3

Length of a lunar month

(time taken for Moon to make one complete orbit)

$=27.32$ days $= 27.32 \times 24 \times 3600$ sec

$= 2.36 \times 10^6$ seconds.

This is easily measured by counting the number of days taken for several lunar months.

Fact 4

Acceleration of falling objects on Earth = $9.8 m/s^2$.

Measured by Galileo, who died the year Newton was born.

Newton's ideas

Idea 1 The force used to keep an object rotating in a circle depends on the object's speed and the circle's radius in this way:- $F = m v^2 / r$

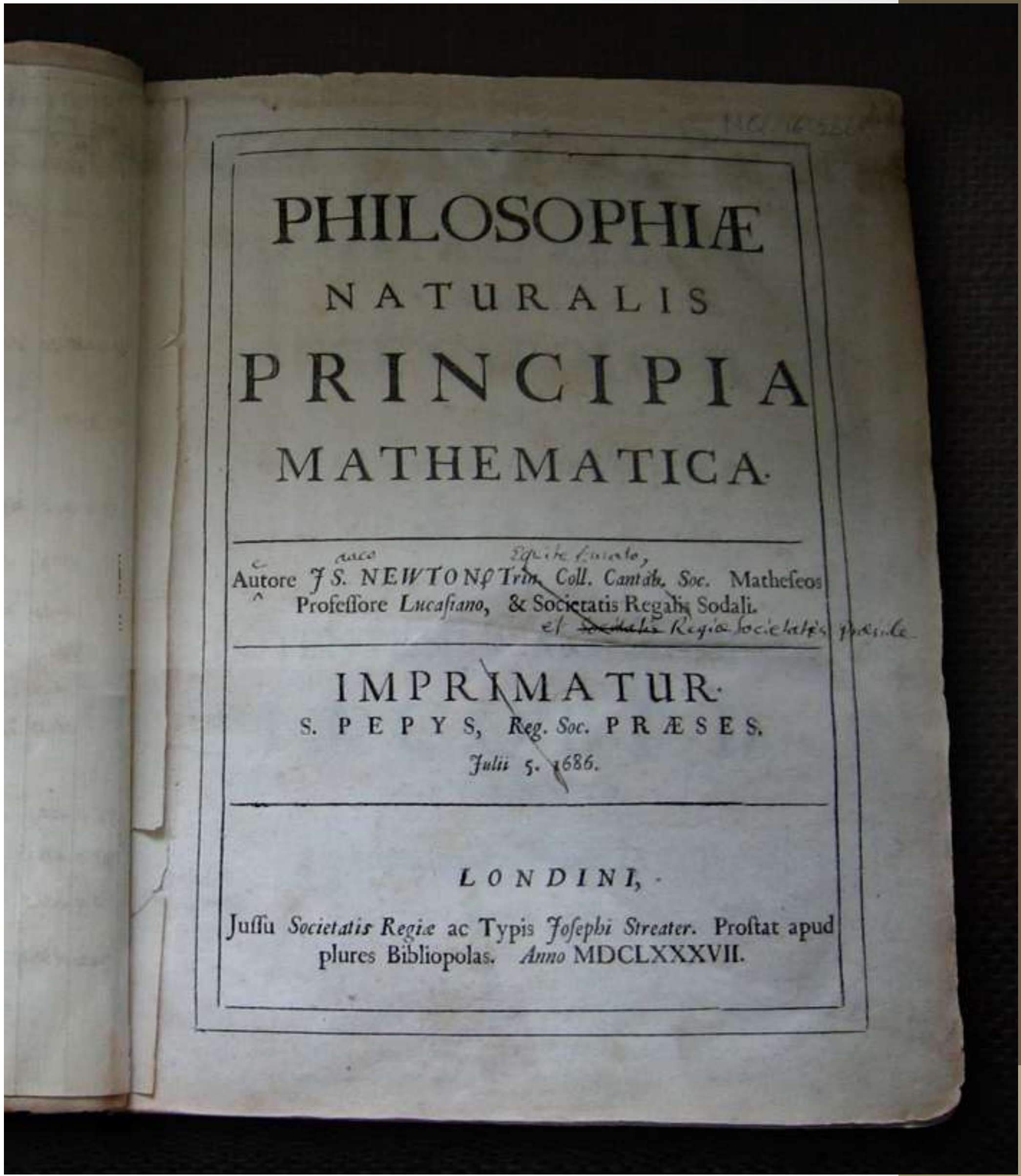
This implies that the *centripetal acceleration* (directed towards the centre on the circle)

is equal to v^2 / r.

This was proved in Newton's Principia.

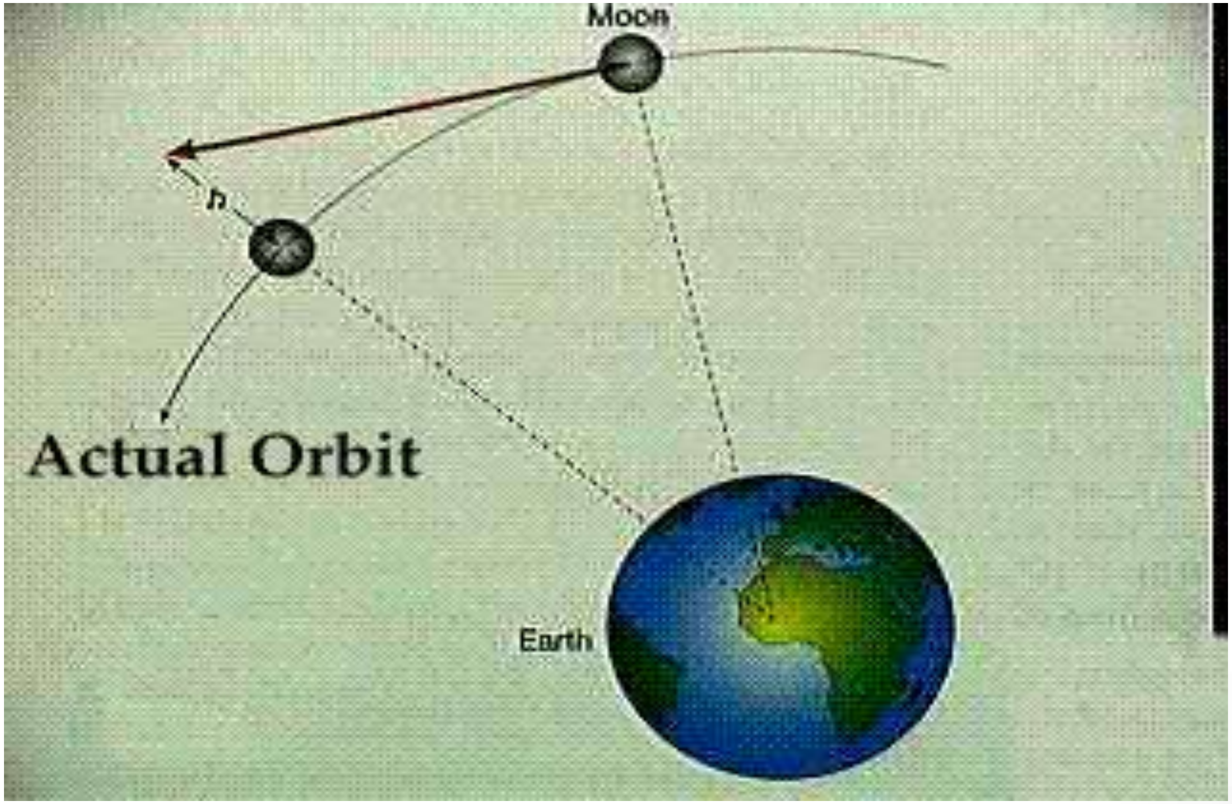
This is his own copy.

Possibly the first proof.



Idea 2

The Moon is in orbit around the Earth because gravity supplies this centripetal force.



Idea 3

This gravitational force is proportional to 1 / (distance from Earth's centre)^2.

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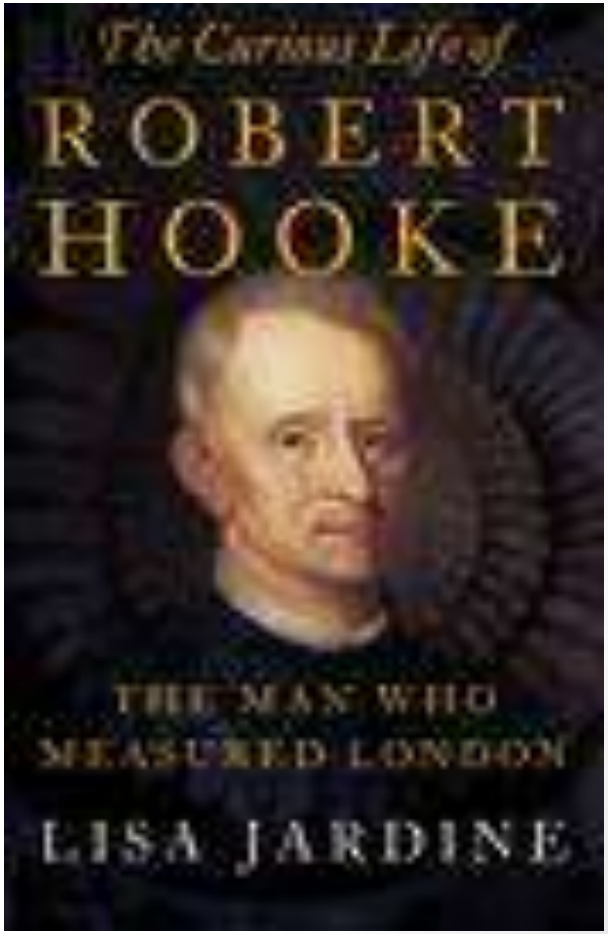
Idea 3 - was possibly also suggested by Robert Hooke – with whom Newton had a continuing row for about 20 years



Newton had all the ingredients, now let's see how he made a good stew!

There are two places where we can compare the Earth's gravitational field:

one at the Earth's surface

and the other at the orbit of the Moon.

This uses idea 3.

Idea 3

$$\frac{\text{Gravitational acc}^n \text{ at the Earth's surface } (g_e)}{\text{Grav. acc}^n \text{ at the distance of the Moon's orbit } (g_m)}$$

$$\frac{g_e}{g_m} = \frac{1 / (\text{radius of Earth})^2}{1 / (\text{radius of Moon's orbit})^2}$$

$$= \frac{(\text{radius of Moon's orbit})^2}{(\text{radius of Earth})^2}$$

$$= R_{mo}^2 / R_e^2$$

Rearranging slightly

$$g_e = \frac{R_{mo}^2 \times \text{centripetal acc}^n \text{ of Moon}(g_m)}{R_e^2}$$

to get a numerical value for g_e, all we need to do is to insert the centripetal acceleration from *Idea 1* and the known value of the ratio of the orbital sizes (60/1).

Idea 1

Centripetal acc^n of Moon = v^2 / R_{mo}

First - the Moon's velocity, v,

$$= \frac{\text{circumference of Moon's orbit}}{\text{time for one revolution}}$$

$= 2\pi R_{mo} / 2.36 \times 10^6 = 1019 m/s$

and, second, the acc^n of Moon,

$$g_m = \frac{v^2}{R_{mo}} = \frac{1019^2}{R_{mo}} = \frac{1.038\times10^6}{R_{mo}}$$

$$= 1.038\times10^6 / (60 \times R_e)$$

$$= 1.038\times10^6/(60 \times 6.38 \times 10^6)$$

$$g_m = 0.00271 m/s^2$$

Now we can substitute this into our expression for g_e

$$g_e = \frac{R_{mo}^2 \times g_m}{R_e^2}$$

where $R_{mo}^2 / R_e^2 = 60^2$

and so, finally,

$$g_e = 60^2 \times 0.00271 m/s^2$$

$$g_e = 9.8 m/s^2$$

which agrees with Galileo's measured value!

and you say

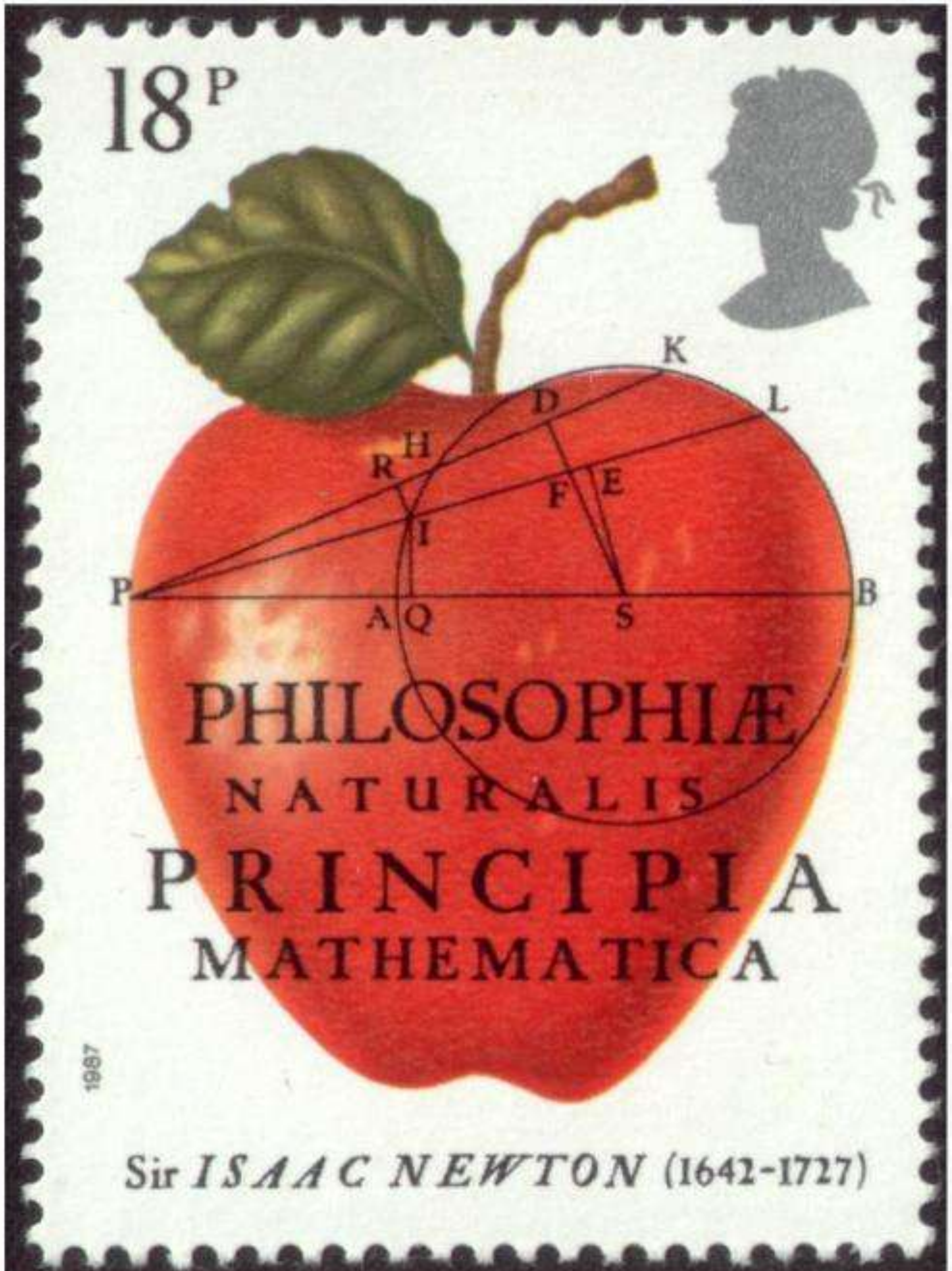
"Wasn't that really neat of him to calculate g_e so accurately from all that data about the moon?"

or you should, if you haven't!

Conclusion

The next step was to extend this idea to the whole of the solar system and then to the rest of the universe. It has become the 'Universal Law of Gravitation'.

Newton's ideas are only superseded by those of Einstein under extreme conditions, so he was right to a high degree of approximation.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MATHEMATICA
1987
Sir ISAAC NEWTON (1642-1727)