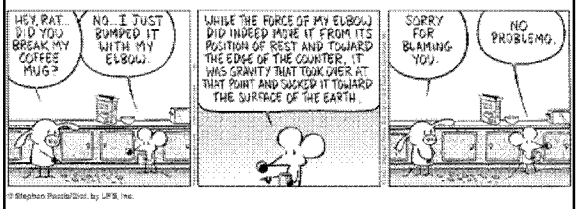
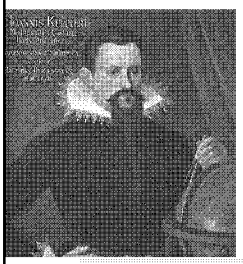
Gravity for Beginners



Monday, October 12

Next Planetarium Show: Tue, Oct 27

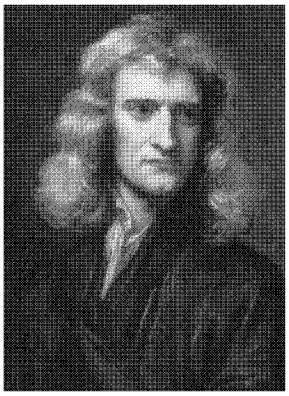
Flashback:



Kepler's 1st Law of Planetary Motion:

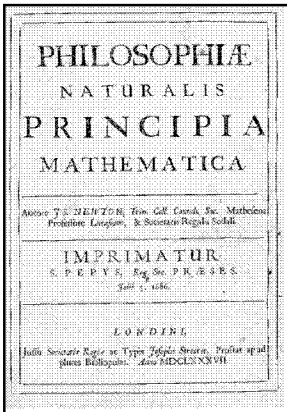
Orbits of planets around the Sun are **ellipses** with the Sun at one **focus**.

Kepler could ***describe*** orbits, but not provide a motivation.



Isaac Newton (1642/3-1727), English

Discovered 3 Laws of Motion, Law of Gravity: explained Kepler.


PHILOSOPHIÆ
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S. PEPYS, Reg. Soc. PRÆSES.

LONDINI

"Mathematical Principles of Natural Philosophy"

Newton's laws: mathematical in form, universal in scope.

First Law of Motion:
An object remains at rest, or moves in a straight line at constant speed, unless acted on by an outside force.

Precise mathematical laws require precise definitions of terms.

SPEED = rate at which an object changes its position.

Example: 65 miles per hour.

VELOCITY = speed *plus* direction of travel

Example: 65 miles per hour to the north.

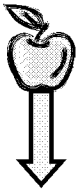
ACCELERATION = rate at which an object changes its *velocity.*

Acceleration can involve:

1) increase in speed 

2) decrease in speed 

3) change in direction. 



Example of acceleration: an apple falls from a tree.

Acceleration = 9.8 meters/second/second.

After 1 second, speed = 9.8 meters/second,

After 2 seconds, speed = 19.6 m/sec, etc…

FORCE = a push or pull acting to accelerate an object.

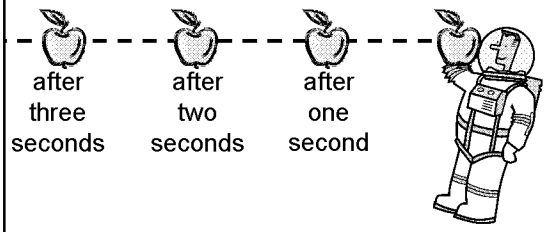
Examples:

Gravity = pull

Electrostatic attraction = pull

Electrostatic repulsion = push

Restatement of First Law:
In the absence of outside forces, velocity is **constant**.



Second Law of Motion:
The acceleration of an object is directly proportional to the force acting on it, and inversely proportional to its mass.

$$a = F / m$$

or

$$F = m \times a$$

Example: a package of cookies has a mass m = 0.454 kilograms.

It experiences the gravitational acceleration a = 9.8 meters/second^2.

How large is the force acting on the cookies?

$$F = m \times a$$

F = (0.454 kg) (9.8 m/sec^2)

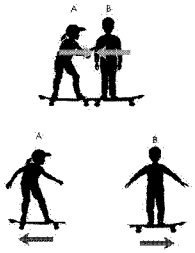
F = 4.4 kg m / s^2

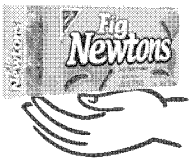
F = 4.4 **Newtons**

F = 1 **pound**

Third Law of Motion:
For every action, there is an equal and opposite reaction.

If A exerts a force on B, then B exerts a force on A that's **equal** in magnitude and **opposite** in direction.





Example: I balance a package of cookies on my hand.

Cookies push on hand:
F = 1 pound, downward.

Hand pushes on cookies:
F = 1 pound, upward.

Example: I remove my hand.

Earth pulls on cookies:
F = 1 pound, downward.

Cookies pull on Earth:
F = 1 pound, upward.

Third Law states:
force on Earth = force on cookies.

Second Law states:
acceleration = force divided by mass.

Mass of Earth = 10^{25} × mass of cookies.
Therefore, acceleration of cookies =
10^{25} times acceleration of Earth.

Newton's Law of Gravity

Gravity is an **attractive** force between **all** pairs of massive objects.

How **big** is the force? That's given by a (fairly) simple formula.

Newton's Law of Gravity

$$F = G \frac{m M}{r^2}$$

F = force

m = mass of one object

M = mass of other object

r = distance between centers of objects

G = "universal constant of gravitation"

($G = 6.7 \times 10^{-11}$ Newton meter^2 / kg^2)

What is gravitational force between Earth and cookies?

$$F = G \frac{m M}{r^2}$$

M = mass of Earth = 6.0×10^{24} kg

m = mass of cookies = 0.454 kg

r = radius of Earth = 6.4×10^{6} meters

G = 6.7×10^{-11} Newton meter^2 / kg^2

F = 4.4 Newtons = 1 pound

What is acceleration of cookies?

Newton's 2nd law of motion:

$$a = F / m$$

Newton's law of gravity:

$$F = G \frac{m M}{r^2}$$

Combining the two equations:

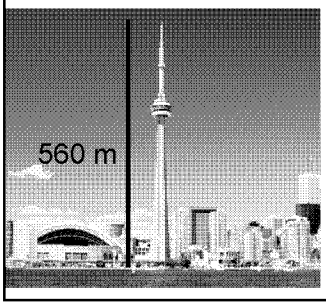
$$a = \frac{G\,m\,M}{r^2} \times \frac{1}{m} = \frac{G\,M}{r^2}$$

For the Earth,

$$a = \frac{G\,M}{r^2} = 9.8 \text{ meters/sec}^2$$

INDEPENDENT OF MASS OF THE COOKIES!

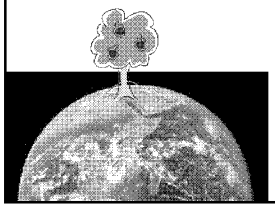
Gravitational acceleration decreases with distance from the Earth's center.



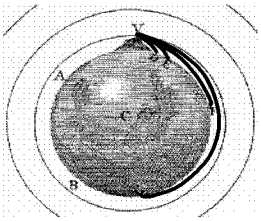
Top of CN Tower: weight = 180 pounds *minus ½ ounce.*

Base of CN Tower: weight = 180 pounds.

Gravity makes apples fall; it also keeps the Moon on its orbit around the Earth, & the Earth on its orbit around the Sun.

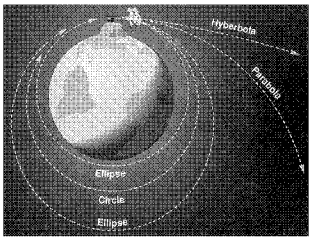


Artificial satellites as envisaged by Newton:



To put an object into orbit, launch it sideways with a large enough speed.

Newton: **shape** of orbit depends on **speed** of satellite at launch.



Low speed = **closed** orbit (circle, ellipse).
High speed = **open** orbit (parabola, hyperbola).

Wednesday's Lecture:

Stars & Galaxies in Motion

Reminders:

Have you read chapters 1 – 4 ?
Problem Set 2 is due **Wednesday**.
Planetarium shows **Oct 27 & 28.**