PHYS11 CH:1 The Rules That Run the Universe

From Atoms to Galaxies

Mr. Gullo

December 2025

Outline

The Mystery

What if one set of rules explained
everything in the universe?

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From the atoms in your fingertips to galaxies 2.5 million light years away...

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The same laws apply.

2.5 Million Light Years Away

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The Mental Model

The force holding you in your seat is the same force arranging billions of stars in Andromeda.

Learning Objectives

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- **1.1:** Distinguish classical physics from modern physics
- **1.1:** Describe how physics is used in other sciences and everyday technology

1.1 The Source Code of Reality

Nature's Operating System

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The Mental Model

Physics is like discovering the source code that runs reality.

1.1 Physics in Your Phone

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Real-World: Smartphone Physics

- Electric circuits and current flow
- GPS: relationship between speed, distance, time
- Screen: optics and light

1.1 Ancient Physics: Stonehenge

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Built 3000-1000 BC as an astronomical observatory.

1.1 Branches of Physics

Classical Physics

- Mechanics (motion)
- Thermodynamics (heat)
- Electricity and Magnetism
- Optics (light)
- Acoustics (sound)

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Modern Physics

- Relativity
- Quantum Mechanics
- Nuclear Physics
- Particle Physics

1.1 The Intuition Trap

Classical physics works when:

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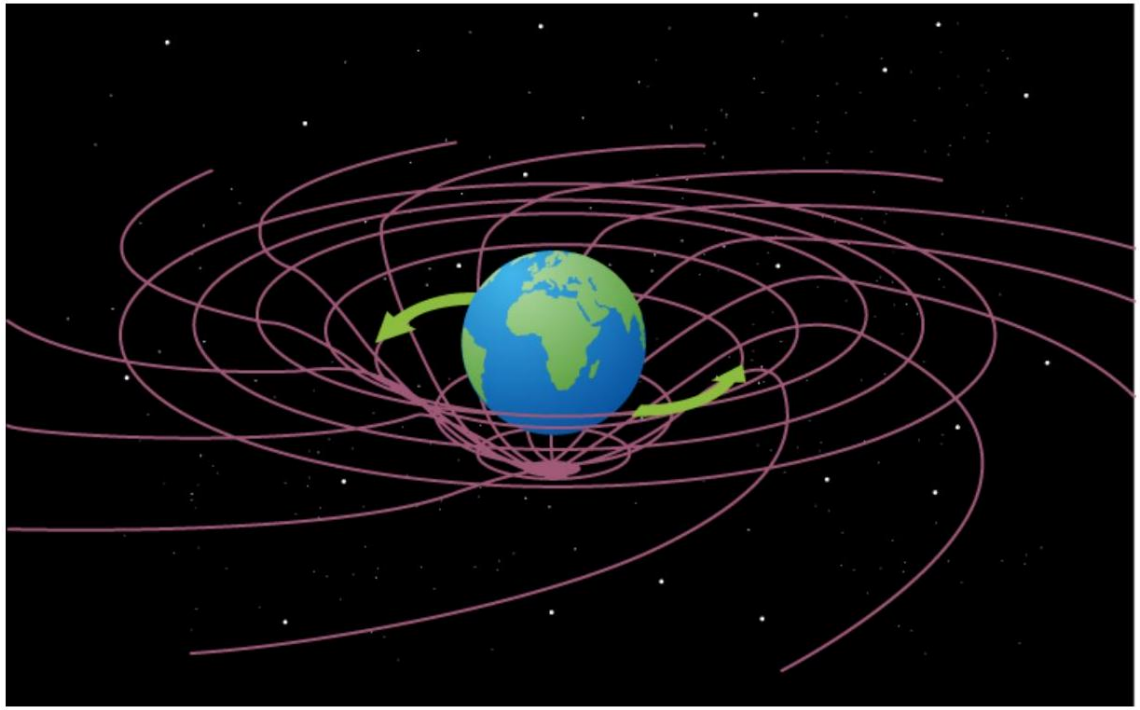
What Your Brain Gets Wrong

Your intuition evolved for everyday speeds and sizes.
At extremes (tiny, fast, massive), **intuition fails completely**.

1.1 Relativity: Time and Space



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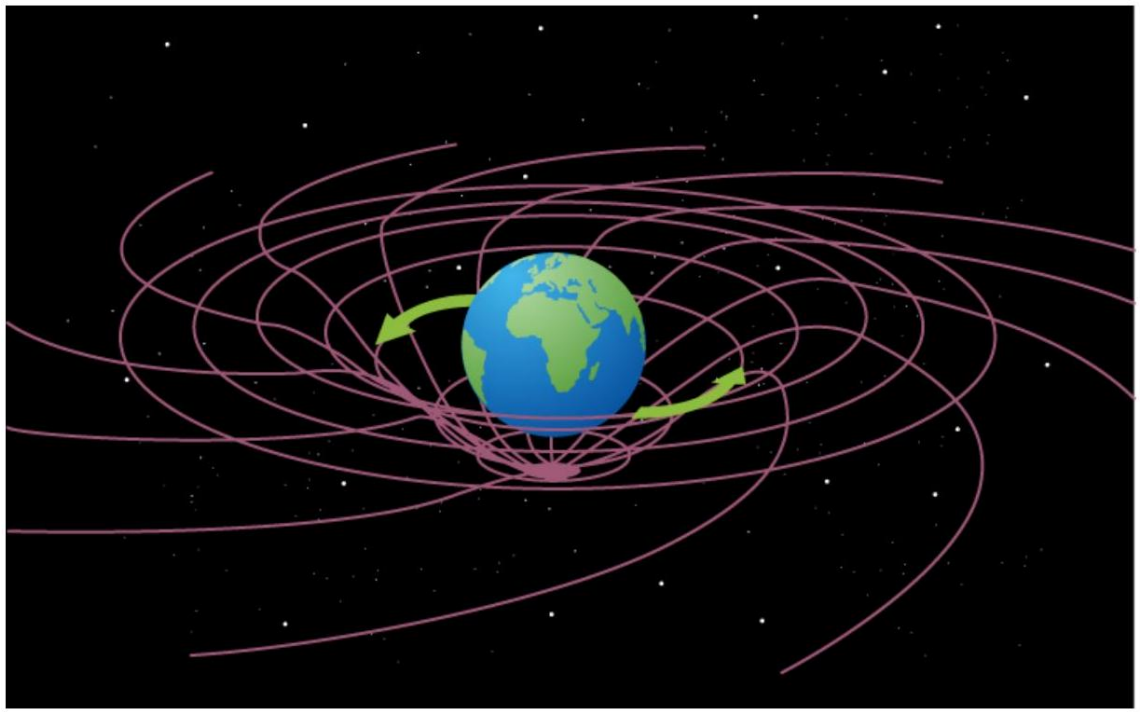
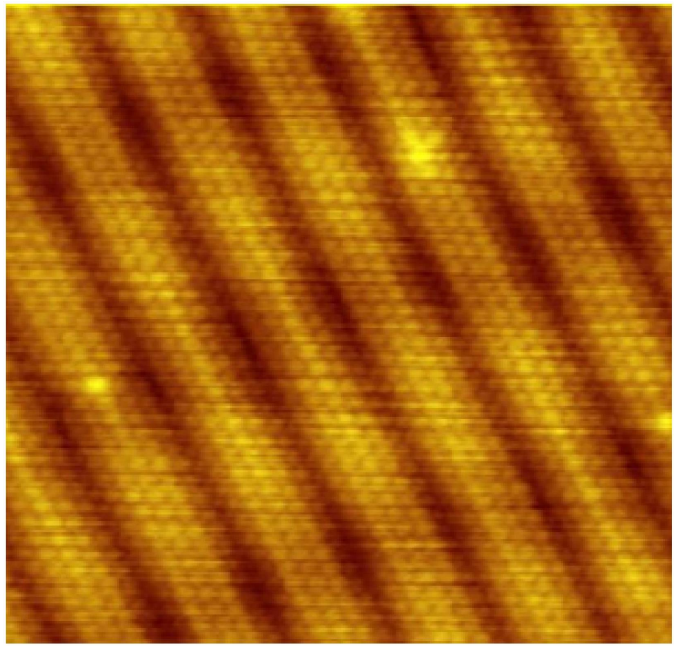


Einstein's discoveries:

- Time slows down at high speeds
- Length contracts at high speeds
- Gravity warps space-time

1.1 Quantum Mechanics



Individual atoms visible with scanning tunneling microscope

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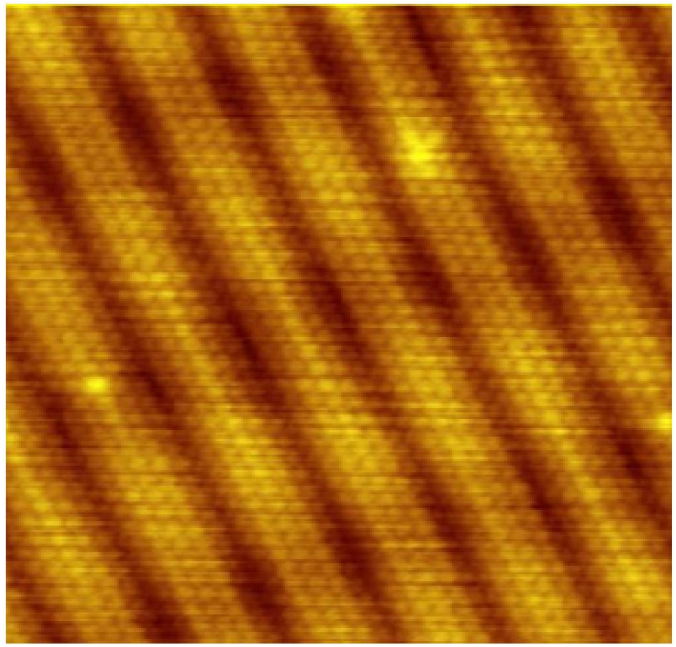

Individual atoms visible with scanning tunneling microscope

Studies:

- Atoms and subatomic particles
- Behavior at tiny scales
- Particles moving near light speed

1.1 Particle Colliders

Fermilab particle accelerator

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Fermilab particle accelerator

Accelerate particles to near light speed to study their properties.

1.1 Microwaves and Metal

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Real-World: Why Metal Sparks

Microwaves increase electron movement in metal $\rightarrow$ electrical current $\rightarrow$ sparks!

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Warning

Never put metal in a microwave - fire hazard!

1.1 Physics in Other Sciences

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- **Chemistry:** atomic and molecular physics

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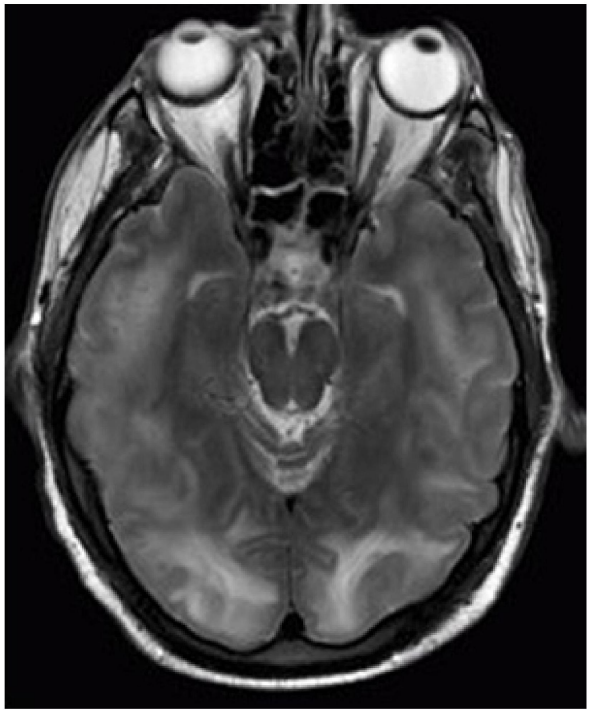
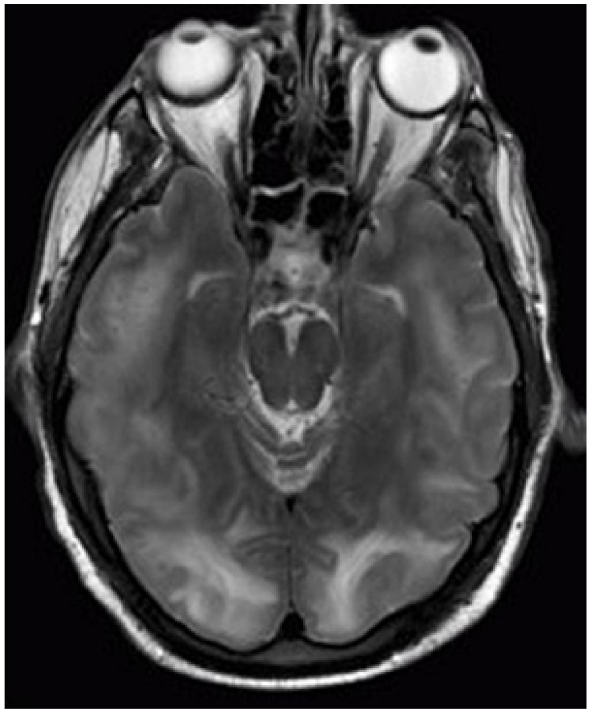
- **Medicine:** X-rays, MRI, ultrasound
- **Geology:** radioactive dating, earthquakes
- **Engineering:** structural design, acoustics
- **Architecture:** stability, heating, lighting

1.1 Medical Applications



MRI scan

1.1 Medical Applications



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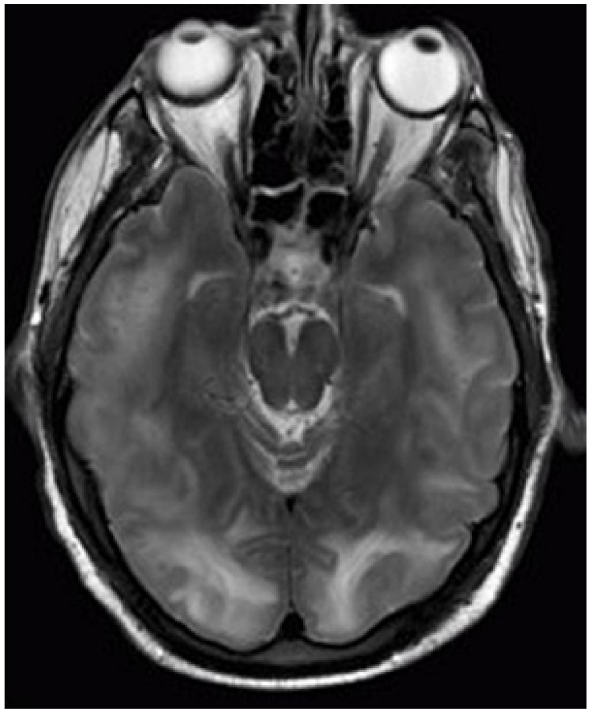
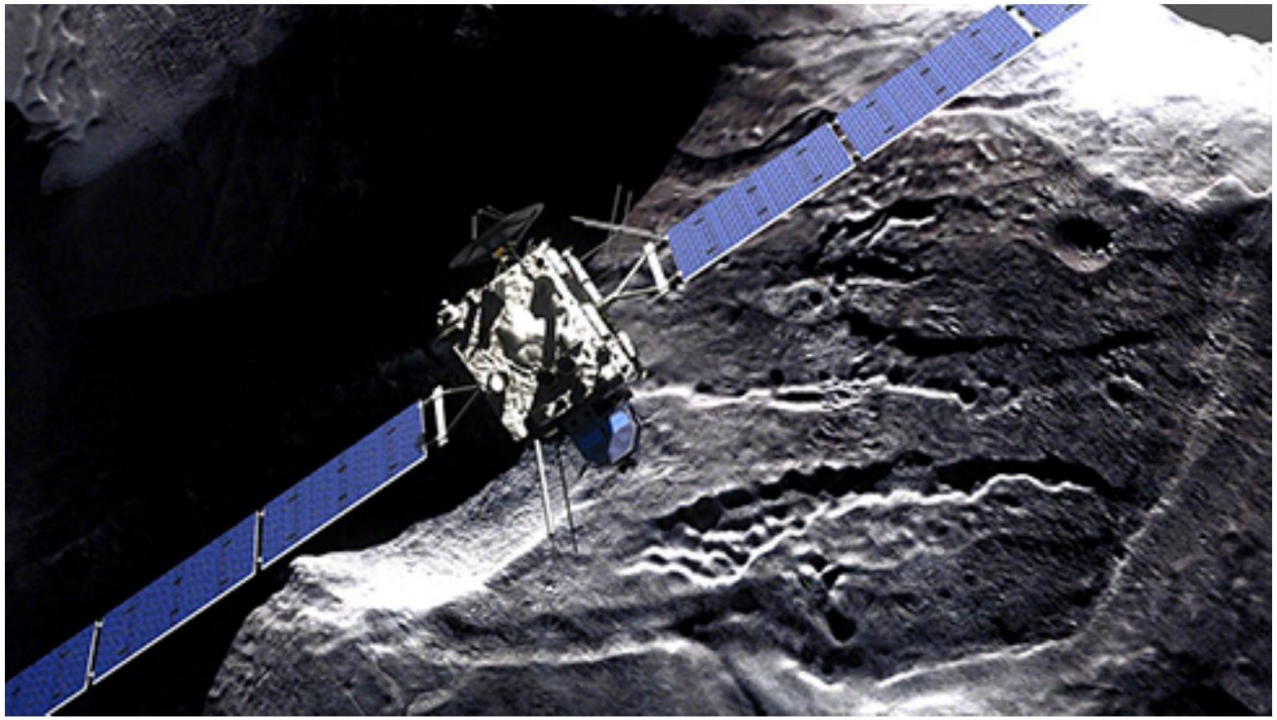


Cell walls

MRI uses electromagnetic waves. Cell walls use physics of selective permeability.

1.1 Rosetta Mission



Rosetta spacecraft with Philae lander

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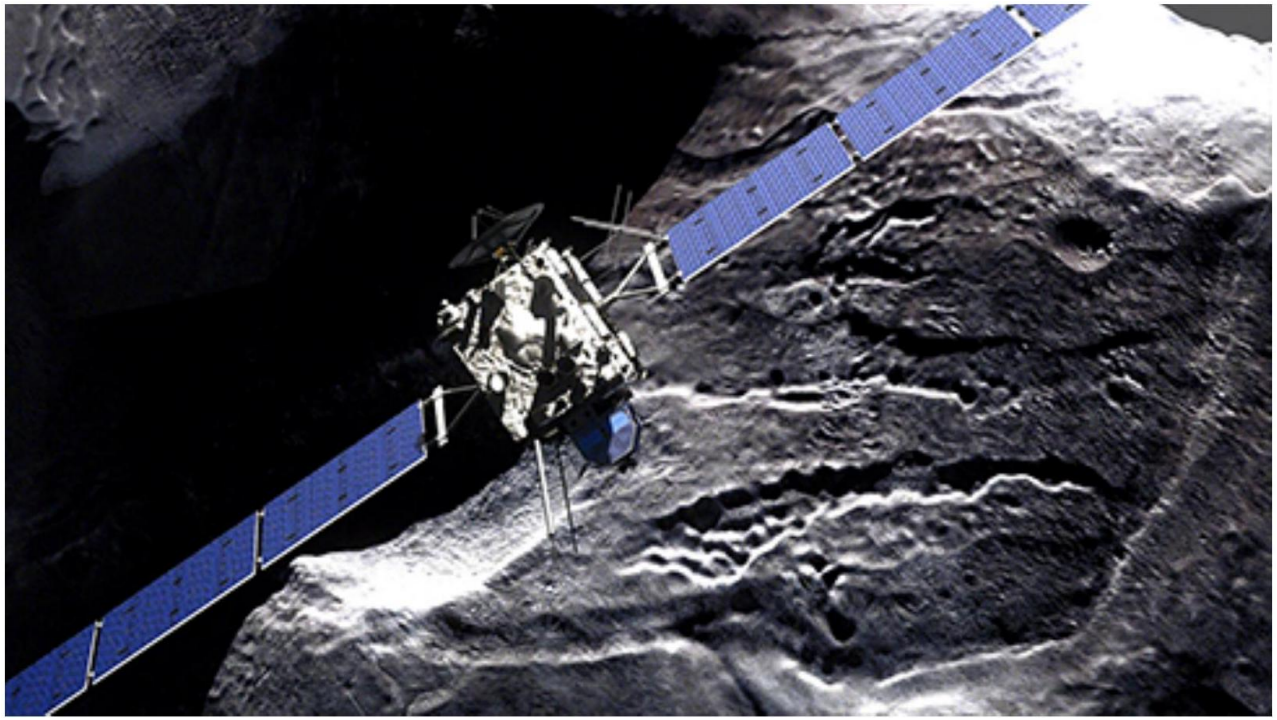
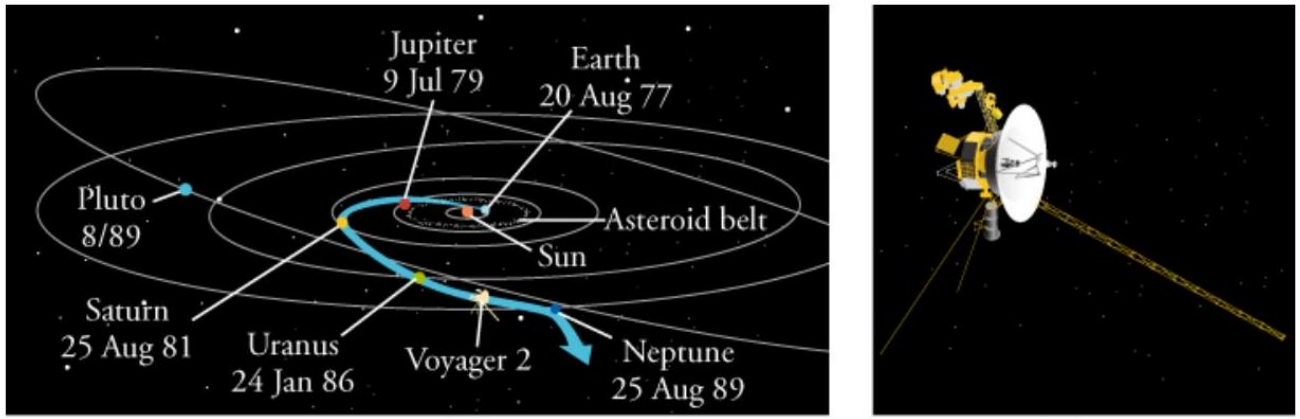


Rosetta spacecraft with Philae lander

Achievement (2014): First spacecraft to orbit and land on a comet.

1.1 Voyager Missions



Voyager trajectory using planetary gravity

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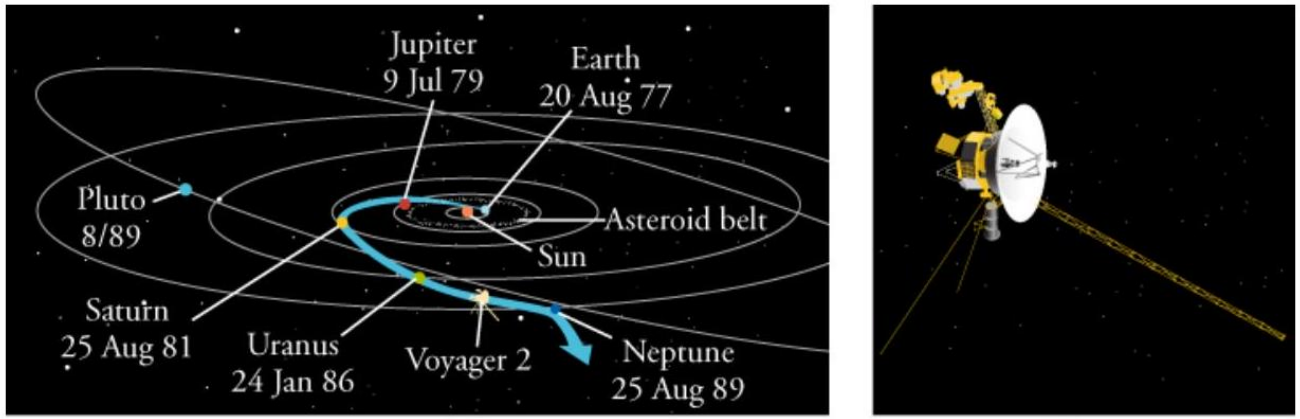

Voyager trajectory using planetary gravity

Voyager 1: Launched 1977, now in interstellar space!

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- **1.2:** Define a scientific model and describe examples
- **1.2:** Compare and contrast hypothesis, theory, and law

1.2 The Scientific Method

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7. Communicate **results**

1.2 Example: Car Won't Start

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Test: Replace fuel pump...

1.2 Scientific Models

Definition: Scientific Model

A representation of something too difficult or impossible to study directly.

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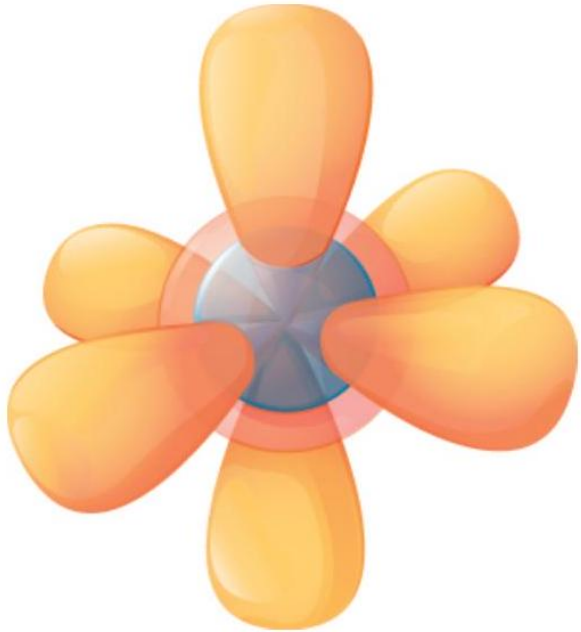
- Computer simulations
- Diagrams and visualizations

1.2 Electron Cloud Model



Electron probability clouds around atom nucleus

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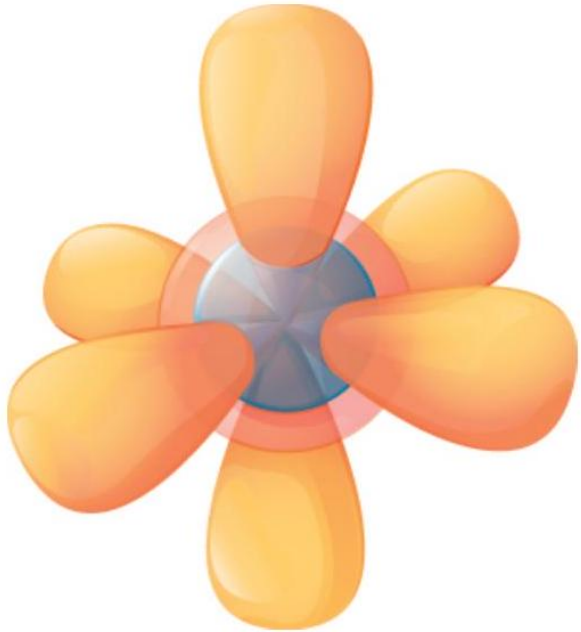

Electron probability clouds around atom nucleus

Shows: Where electrons are likely to be found
Limitation: Cannot show exact position at any moment

1.2 The Vocabulary of Discovery

The Ladder of Certainty

Hypothesis: Educated guess - testable

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Civilian View vs. Reality

Civilian: "It's just a theory" = probably wrong

Physicist: "Theory" = extensively tested and supported

1.2 Nature's Source Code

Scientific laws are:

- Universal (work EVERYWHERE in the cosmos)

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Universal Law: The Pushback

$$\boxed{F = ma}$$

Force equals mass times acceleration. Works on Earth, Mars, and distant galaxies.

1.2 Science Is Self-Correcting

Key point: Even well-established laws and theories can change with new evidence.

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Scientists say theories are **supported**, not **proven**.

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- **1.3:** Use SI units and perform conversions

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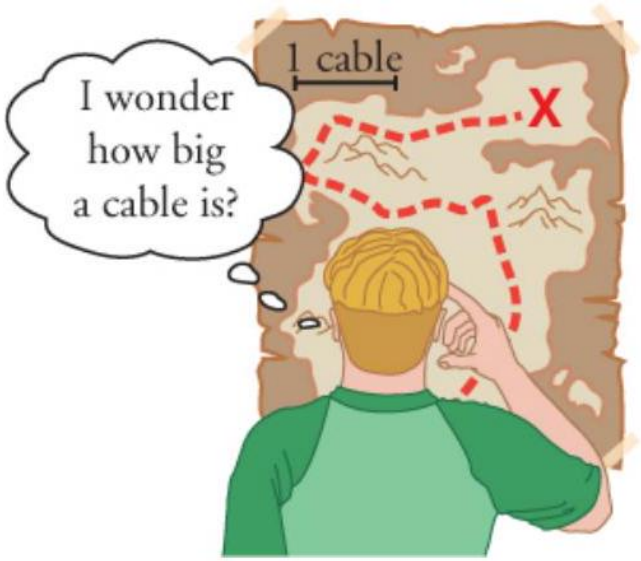
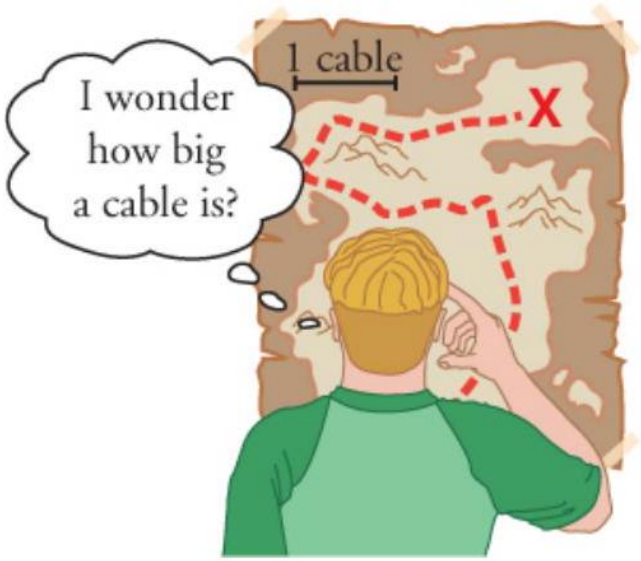
- **1.3:** Apply significant figures in calculations
- **1.3:** Create and interpret graphs of physical relationships

1.3 Standard Units



Distance without units is meaningless!

1.3 Standard Units



Distance without units is meaningless!

Units are standardized values for measurement.
Without them, we can't compare or communicate measurements.

1.3 SI Base Units

Quantity	**SI Unit**
Length	meter (m)
Mass	kilogram (kg)
Time	second (s)
Electric current	ampere (A)
Temperature	kelvin (K)
Amount of substance	mole (mol)
Luminous intensity	candela (cd)

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All other units are **derived** from these seven.

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Current definition (1983):
The distance light travels in a vacuum in $\frac{1}{299{,}792{,}458}$ of a second.

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- 1960: Wavelengths of krypton light
- 1983: Based on speed of light (current)

1.3 The Kilogram

Old definition: Mass of platinum-iridium cylinder in Paris

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Problem: Surface contamination changed mass slightly over time

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New definition (2019): Based on Planck's constant h

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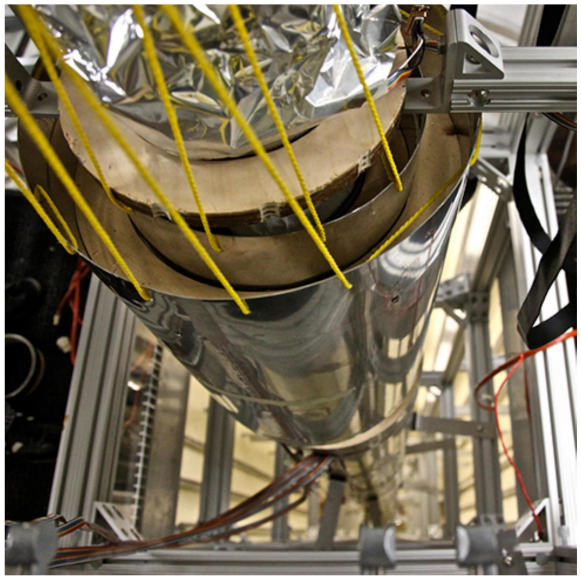
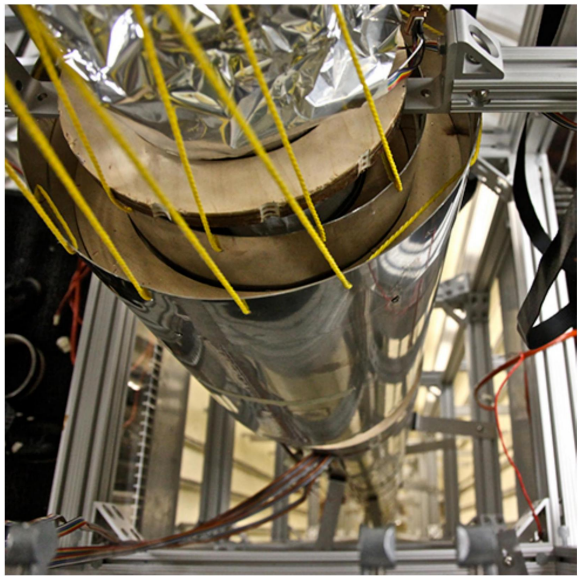
New definition (2019): Based on Planck's constant h
More stable and reproducible!

1.3 The Second



Atomic clock

1.3 The Second



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Definition: Time for 9,192,631,770 cesium atom vibrations

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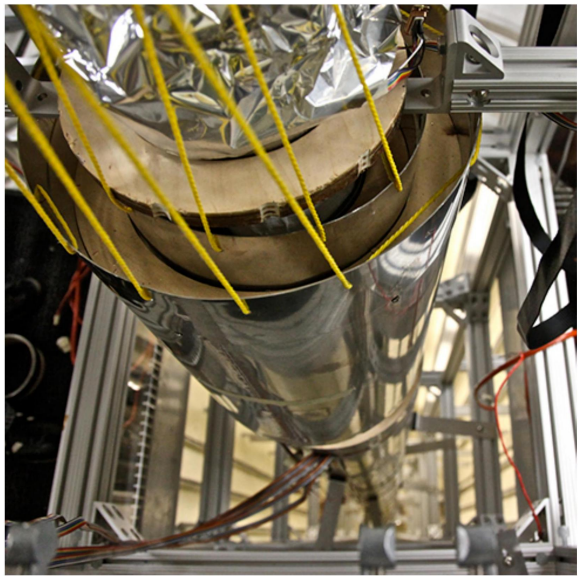

Atomic clock

Definition: Time for 9,192,631,770 cesium atom vibrations
Accurate to one microsecond per year!

1.3 Metric Prefixes

Prefix	**Symbol**	**Power of 10**	**Example**
giga-	G	10^{9}	gigameter
mega-	M	10^{6}	megawatt
kilo-	k	10^{3}	kilometer
(base)	-	10^{0}	meter
centi-	c	10^{-2}	centimeter
milli-	m	10^{-3}	millimeter
micro-	μ	10^{-6}	micrometer
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Conversions are easy - just move decimal point!

1.3 Range of Measurements

- Diameter of proton: 10^{-15} m

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- Distance to nearest star: 10^{16} m

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Physics spans 31 orders of magnitude!

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Examples:

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Positive exponent: Move decimal right (large number)
Negative exponent: Move decimal left (small number)

1.3 Order of Magnitude

Definition: The power of 10 in scientific notation

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Examples:

- $800 = 8 \times 10^2$

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- $800 = 8 \times 10^2$
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Ballpark estimate for scale of a value.

1.3 Unit Conversion

Conversion factor: A ratio equal to 1

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Example: Convert 1 hour to seconds

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$$= 3600\ \text{s} = 3.6 \times 10^3\ \text{s}$$

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Key: Units cancel like algebra!

Attempt: Decoding Motion

The Challenge (3 min, silent)

A car travels 10.0 km in 20.0 min.

Given:

- distance = 10.0 km
- time = 20.0 min

Find: Average speed in km/h

Can you decode this motion? Work silently.

Compare: Unit Conversion

Turn and talk (2 min):

1. What formula did you use for average speed?
2. How did you convert minutes to hours?
3. Did you multiply or divide by 60?

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Name wheel: One pair share your approach (not your answer).

Reveal: The Math of Motion

Self-correct in a different color:

Step 1: Average speed $= \frac{\text{distance}}{\text{time}}$

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Check: 10 km in 1/3 hour = 30 km in 1 hour. Reasonable!

1.3 Accuracy vs Precision

Accuracy

How close measurement is to true value

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How close repeated measurements are to each other

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Accuracy

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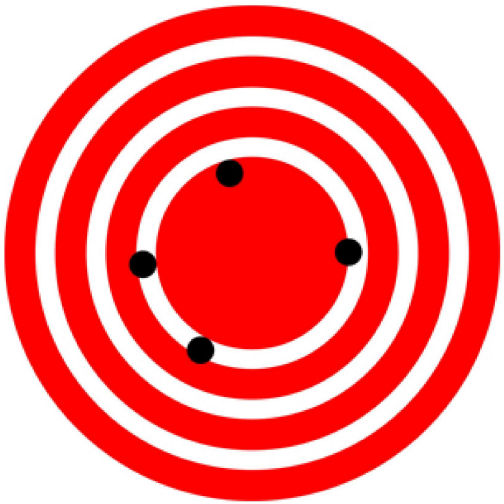
Key Difference

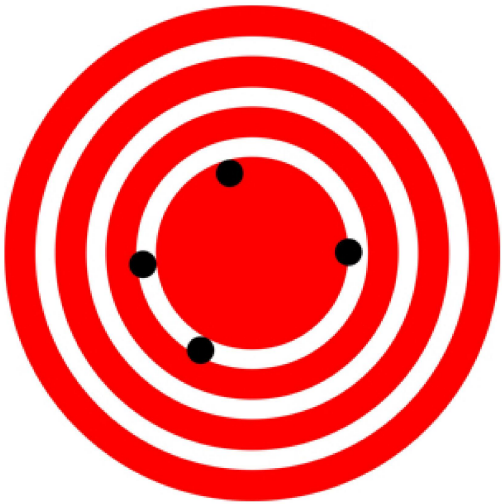
Accuracy = correctness. Precision = consistency. You can have one without the other!

1.3 Target Analogy



Accurate, not precise

1.3 Target Analogy



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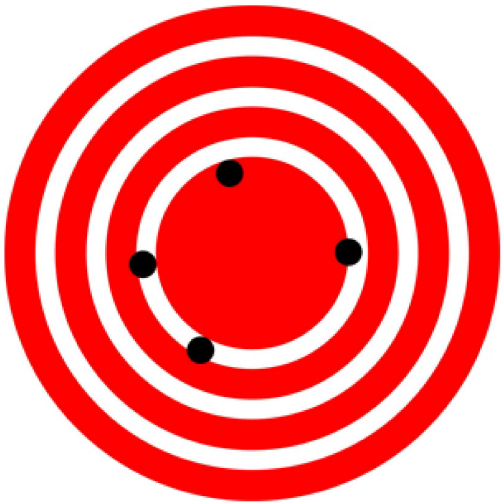

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Accurate and precise

1.3 Significant Figures

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All measured digits plus one estimated digit

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Common Mistake

Leading zeros (0.0045) are NOT significant - they're just placeholders!

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Answer has same number of sig figs as least precise value.

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Round to 2 sig figs: $\boxed{4.5 \text{ m}^2}$

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Notation: 11.0 ± 0.2 inches
Means: actual value between 10.8 and 11.2 inches

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The bag weighs $5 \text{ lb} \pm 8\%$

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4. SI units = universal language of measurement
5. Sig figs = honesty about precision
6. Uncertainty = the humility of science

Key Equations

$$\text{Average speed} = \frac{\text{distance}}{\text{time}} \tag{1}$$

$$\text{Percent uncertainty} = \frac{\delta A}{A} \times 100\% \tag{2}$$

Homework

Complete the assigned problems

posted on the LMS