

PHYS11 CH:1 The Rules That Run the Universe

From Atoms to Galaxies

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Outline

- 1 Introduction
- 2 Physics: Definitions and Applications
- 3 The Scientific Methods
- 4 Physical Quantities and Units
- 5 Summary

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

The same laws apply.

2.5 Million Light Years Away



2.5 Million Light Years Away



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



1.1 Ancient Physics: Stonehenge



Built 3000-1000 BC as an astronomical observatory.

1.1 Branches of Physics

Classical Physics

- Mechanics (motion)
- Thermodynamics (heat)
- Electricity and Magnetism
- Optics (light)
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Modern Physics

- Relativity
- Quantum Mechanics
- Nuclear Physics
- Particle Physics

1.1 The Intuition Trap

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- ① Speeds less than 1% of light speed

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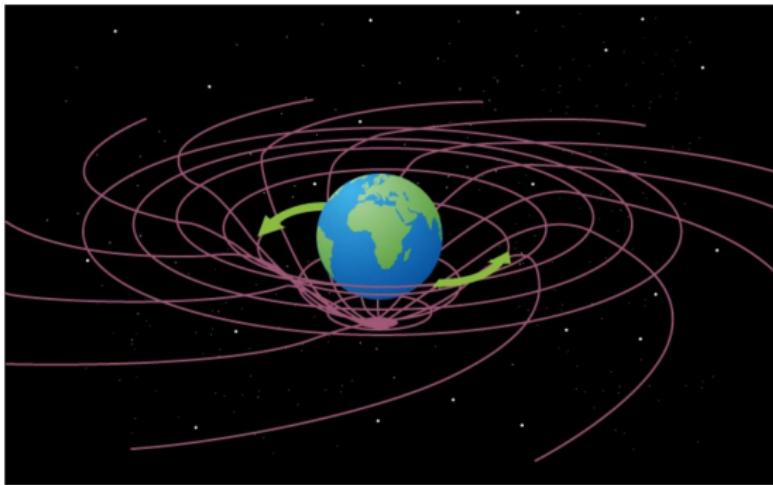
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What Your Brain Gets Wrong

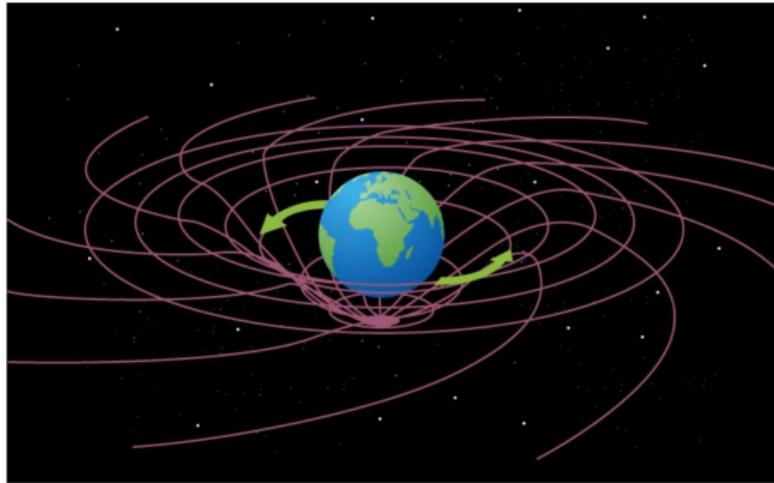
Your intuition evolved for everyday speeds and sizes.

At extremes (tiny, fast, massive), **intuition fails completely.**

1.1 Relativity: Time and Space



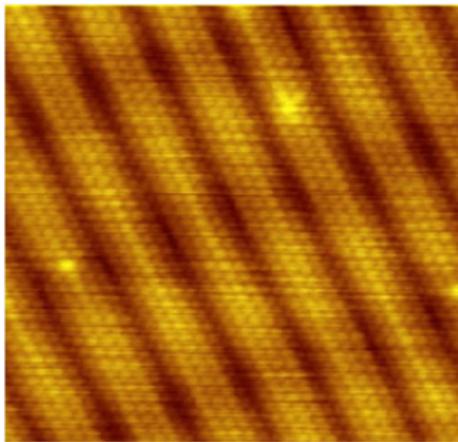
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Einstein's discoveries:

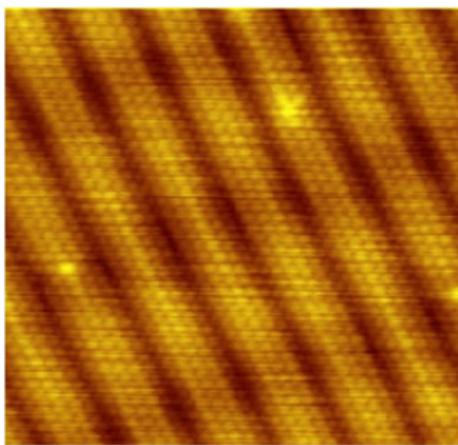
- Time slows down at high speeds
- Length contracts at high speeds
- Gravity warps space-time

1.1 Quantum Mechanics



Individual atoms visible with scanning tunneling microscope

1.1 Quantum Mechanics



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

1.1 Particle Colliders



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 → electrical current → sparks!

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Warning

Never put metal in a microwave - fire hazard!

1.1 Physics in Other Sciences

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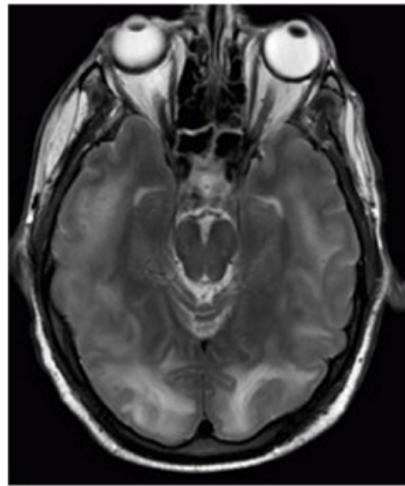
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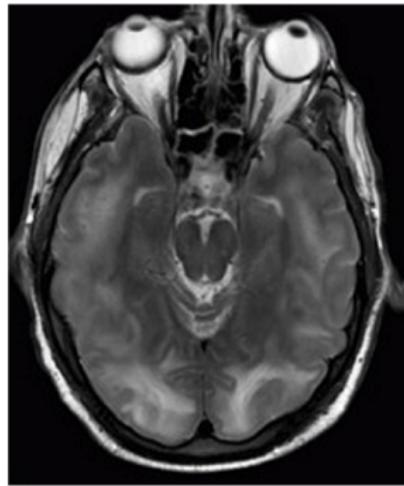
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- **Engineering:** structural design, acoustics
- **Architecture:** stability, heating, lighting

1.1 Medical Applications

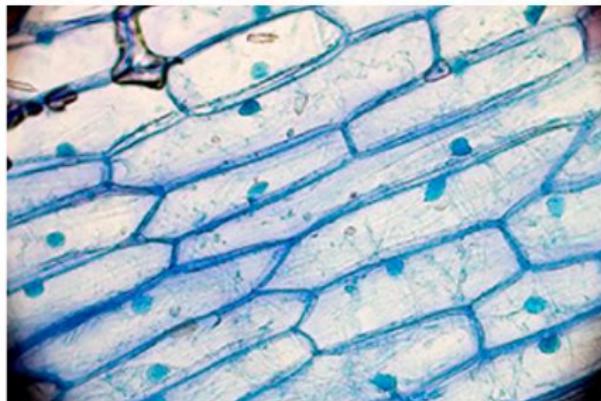


MRI scan

1.1 Medical Applications



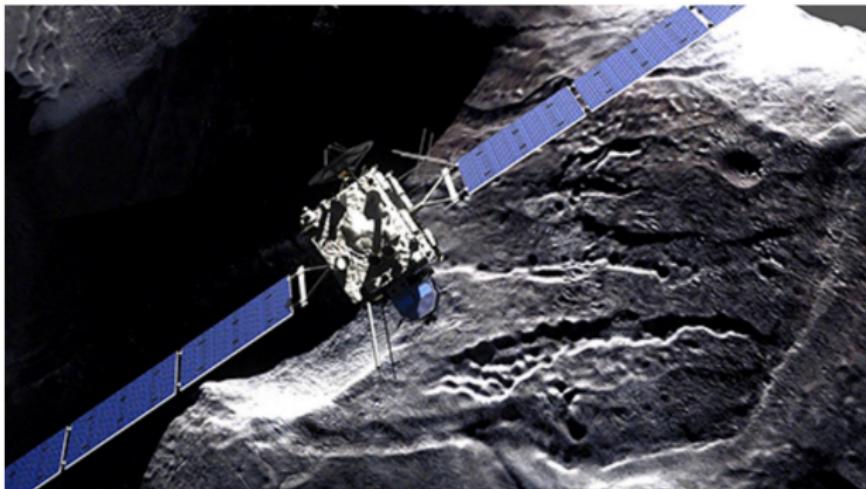
MRI scan



Cell walls

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

1.1 Rosetta Mission



Rosetta spacecraft with Philae lander

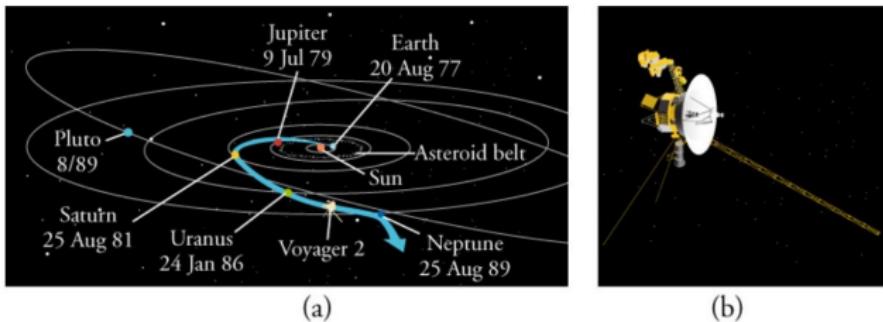
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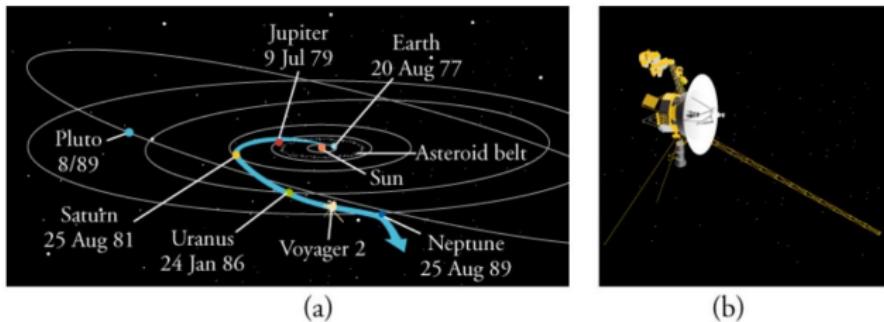
Achievement (2014): First spacecraft to orbit and land on a comet.

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**

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Test: Replace fuel pump...

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Definition: Scientific Model

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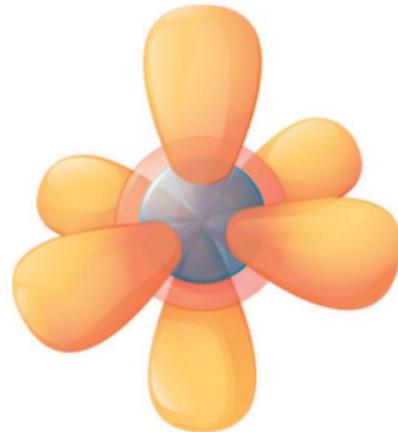
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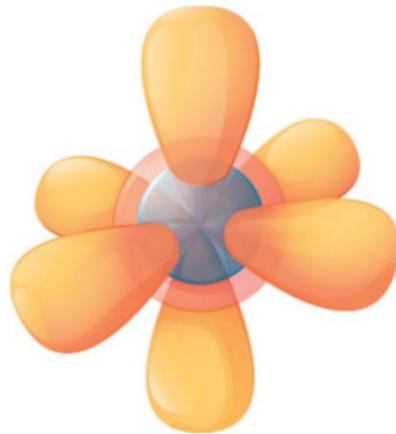
- Physical models (3D atom model)
- Mathematical equations
- Computer simulations
- Diagrams and visualizations

1.2 Electron Cloud Model



Electron probability clouds around atom nucleus

1.2 Electron Cloud Model



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

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Universal Law: The Pushback

$$F = ma$$

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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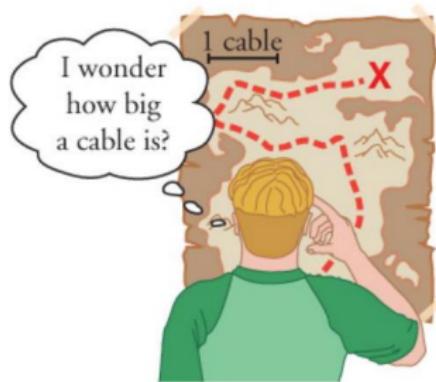
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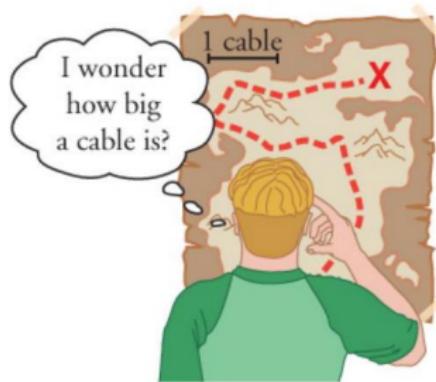
- **1.3:** Use SI units and perform conversions
- **1.3:** Apply significant figures in calculations
- **1.3:** Create and interpret graphs of physical relationships

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

1.3 The Kilogram

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Problem: Surface contamination changed mass slightly over time

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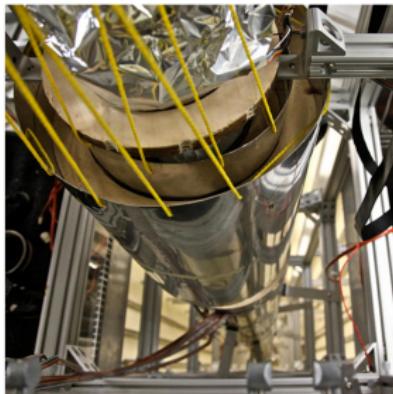
More stable and reproducible!

1.3 The Second



Atomic clock

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Atomic clock

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

1.3 The Second



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
nano-	n	10^{-9}	nanometer

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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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Physics spans 31 orders of magnitude!

1.3 Scientific Notation

Format: $x \times 10^y$

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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:

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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

$$\begin{aligned}1 \text{ h} &\times \frac{60 \text{ min}}{1 \text{ h}} \times \frac{60 \text{ s}}{1 \text{ min}} \\&= 3600 \text{ s} = 3.6 \times 10^3 \text{ s}\end{aligned}$$

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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 = $\frac{\text{distance}}{\text{time}}$

Reveal: The Math of Motion

Self-correct in a different color:

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

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$$0.500 \frac{\text{km}}{\text{min}} \times \frac{60 \text{ min}}{1 \text{ h}} = \boxed{30.0 \text{ km/h}}$$

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$$0.500 \frac{\text{km}}{\text{min}} \times \frac{60 \text{ min}}{1 \text{ h}} = \boxed{30.0 \text{ km/h}}$$

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

1.3 Accuracy vs Precision

Accuracy

How close measurement is to true value

Precision

How close repeated measurements are to each other

1.3 Accuracy vs Precision

Accuracy

How close measurement is to true value

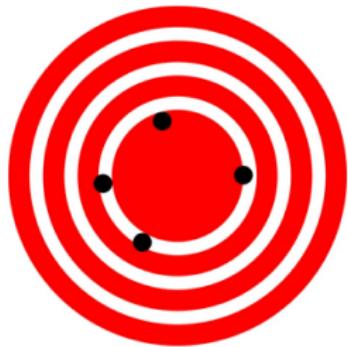
Precision

How close repeated measurements are to each other

Key Difference

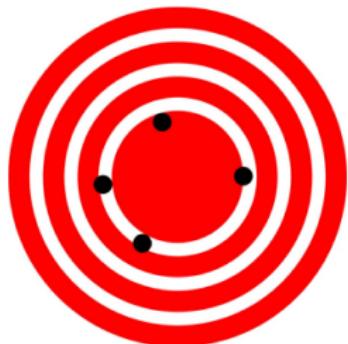
Accuracy = correctness. Precision = consistency. You can have one without the other!

1.3 Target Analogy



Accurate, not precise

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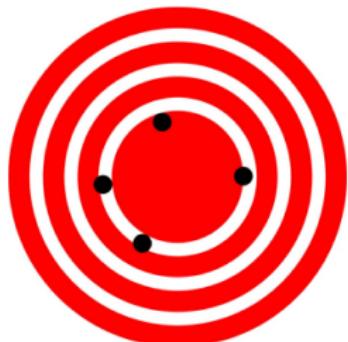


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Precise, not accurate

1.3 Target Analogy



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Precise, not accurate



Accurate and precise

1.3 Significant Figures

Definition: Significant Figures

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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Round to 2 sig figs: 4.5 m²

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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 lb $\pm 8\%$

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The Revelations

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- ⑤ Sig figs = honesty about precision
- ⑥ Uncertainty = the humility of science

Key Equations

$$\text{Average speed} = \frac{\text{distance}}{\text{time}} \quad (1)$$

$$\text{Percent uncertainty} = \frac{\delta A}{A} \times 100\% \quad (2)$$

Homework

Complete the assigned problems
posted on the LMS