PHYS11 CH:1 The Rules That Run the Universe

From Atoms to Galaxies

Mr. Gullo

December 2025

Outline

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

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

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

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

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

The same laws apply.

The Mental Model

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

Learning Objectives

By the end of this lesson, you will be able to:

- **1.1:** Describe the definition, aims, and branches of physics

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- **1.1:** Describe the definition, aims, and branches of physics
- **1.1:** Distinguish classical physics from modern physics
- **1.1:** Describe how physics is used in other sciences and everyday technology

Nature's Operating System

Physics is the science of the fundamental rules governing our universe.

1.1 The Source Code of Reality

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- Must be testable - if you can't test it, it's not physics

1.1 The Source Code of Reality

Nature's Operating System

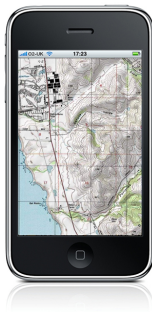Physics is the science of the fundamental rules governing our universe.

What makes it physics:

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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

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

Classical physics works when:

1. Speeds less than 1% of light speed

1.1 The Intuition Trap

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Classical physics works when:

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2. Objects visible to naked eye
3. Weak gravity (like Earth's)

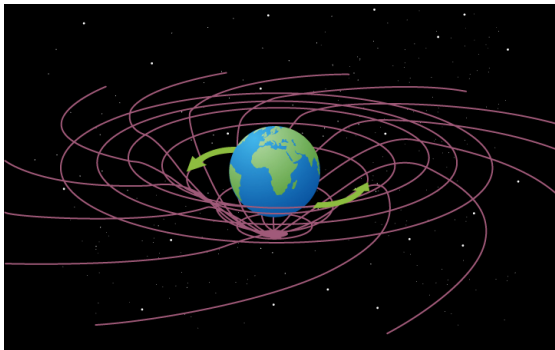# 1.1 The Intuition Trap

Classical physics works when:

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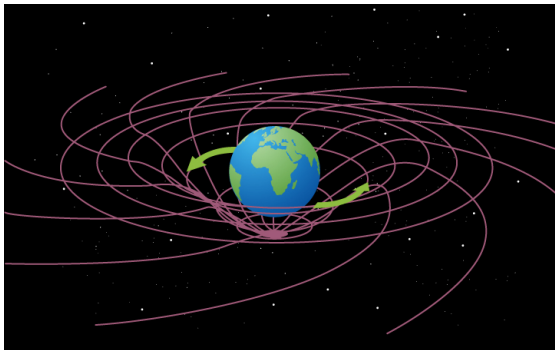3. Weak gravity (like Earth's)

What Your Brain Gets Wrong

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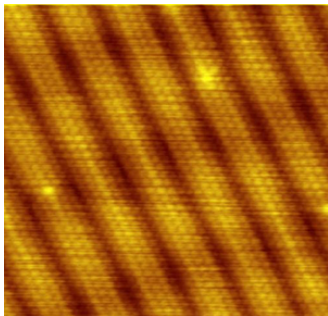
1.1 Relativity: Time and Space

Einstein's discoveries:
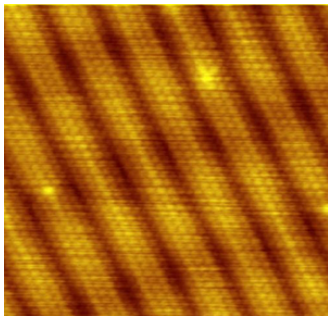
- Time slows down at high speeds
- Length contracts at high speeds
- Gravity warps space-time

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
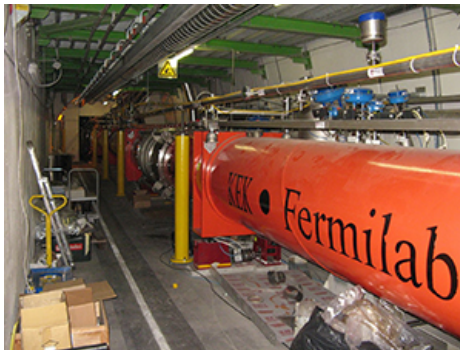
Fermilab particle accelerator
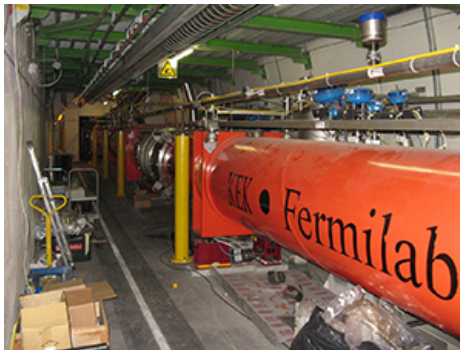
Fermilab particle accelerator

Accelerate particles to near light speed to study their properties.

1.1 Microwaves and Metal

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!

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- **Chemistry:** atomic and molecular physics

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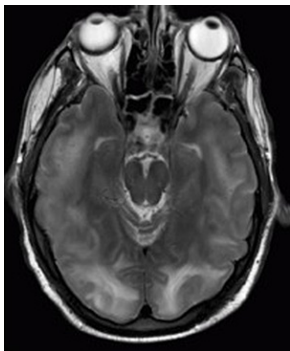
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- **Engineering:** structural design, acoustics
- **Architecture:** stability, heating, lighting

MRI scan

1.1 Medical Applications
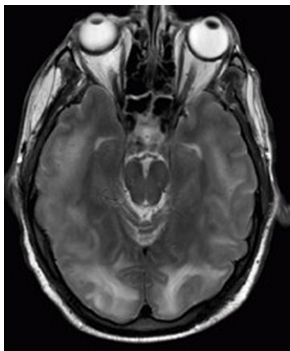
MRI scan
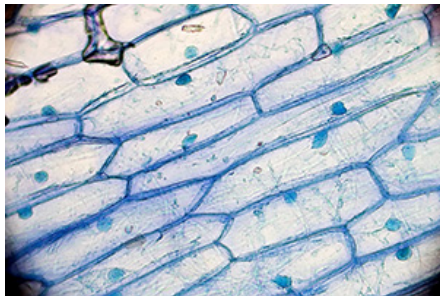
Cell walls

MRI uses electromagnetic waves. Cell walls use physics of selective permeability.
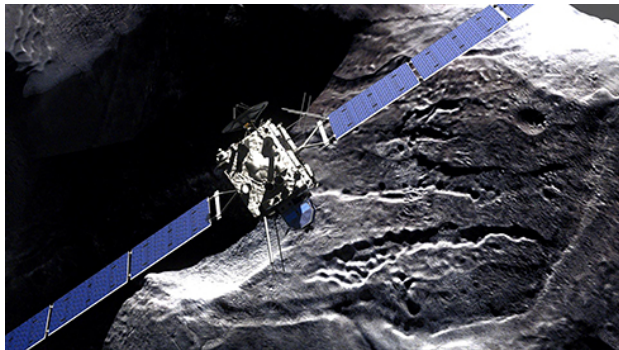
Rosetta spacecraft with Philae lander
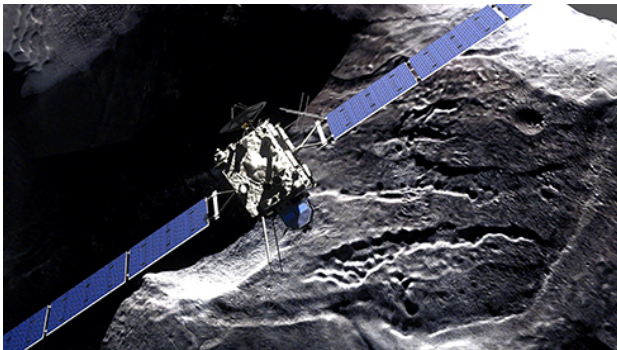
Rosetta spacecraft with Philae lander

Achievement (2014): First spacecraft to orbit and land on a comet.
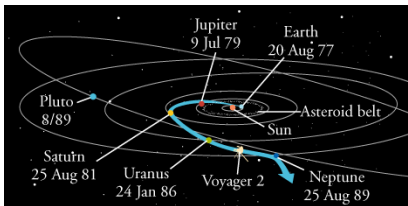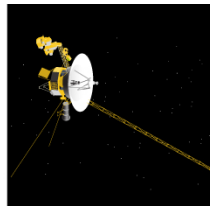
Voyager trajectory using planetary gravity
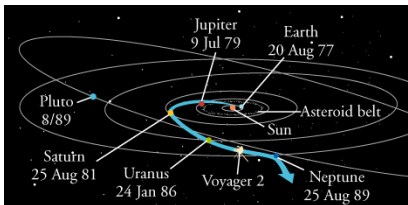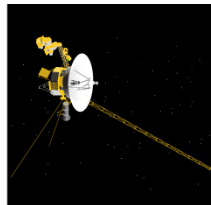
Voyager trajectory using planetary gravity

Voyager 1: Launched 1977, now in interstellar space!

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- **1.2:** Explain how the methods of science are used to make discoveries
- **1.2:** Define a scientific model and describe examples
- **1.2:** Compare and contrast hypothesis, theory, and law

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1.2 The Scientific Method

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7. Communicate **results**

Observation: Car won't start

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Hypothesis 2: Fuel pump is broken
Test: Replace fuel pump...

Definition: Scientific Model

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

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Types of models:

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- Diagrams and visualizations
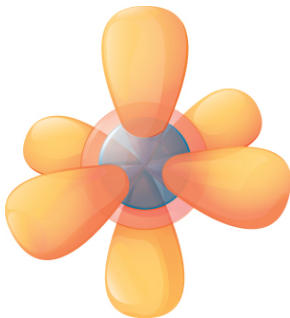
Electron probability clouds around atom nucleus
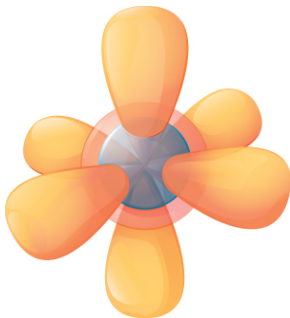
Electron probability clouds around atom nucleus

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

The Ladder of Certainty

Hypothesis: Educated guess - testable

1.2 The Vocabulary of Discovery

The Ladder of Certainty

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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

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Universal Law: The Pushback

$$F = ma$$

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

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

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- **1.3:** Apply significant figures in calculations
- **1.3:** Create and interpret graphs of physical relationships
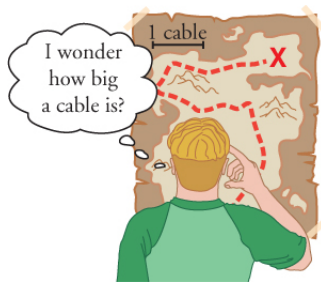
Distance without units is meaningless!
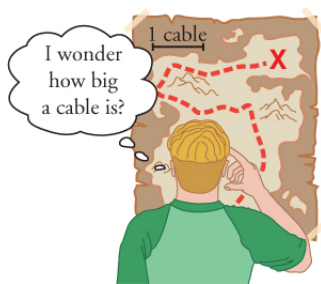
Distance without units is meaningless!

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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The distance light travels in a vacuum in $\frac{1}{299,792,458}$ of a second.

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- 1983: Based on speed of light (current)

1.3 The Kilogram

Old definition: Mass of platinum-iridium cylinder in Paris

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

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More stable and reproducible!
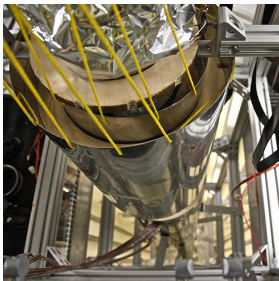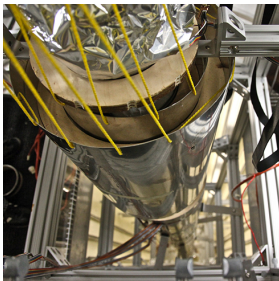
Atomic clock

Atomic clock

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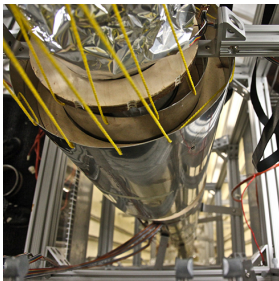
Atomic clock

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

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Physics spans 31 orders of magnitude!

Format: $x \times 10^y$

1.3 Scientific Notation

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Examples:

- $840,000,000,000,000 = 8.4 \times 10^{14}$

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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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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

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

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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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Turn and talk (2 min):

1. What formula did you use for average speed?
2. How did you convert minutes to hours?
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Name wheel: One pair share your approach (not your answer).

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

Step 2: $\frac{10.0 \text{ km}}{20.0 \text{ min}} = 0.500 \frac{\text{km}}{\text{min}}$

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

Reveal: The Math of Motion

Self-correct in a different color:

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

Step 2: $\frac{10.0 \text{ km}}{20.0 \text{ min}} = 0.500 \frac{\text{km}}{\text{min}}$

Step 3: Convert using $\frac{60 \text{ min}}{1 \text{ h}}$

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

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

Accuracy

How close measurement is to true value

1.3 Accuracy vs Precision

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

Accurate, not precise

Accurate, not precise

Precise, not accurate

Accurate, not precise   Precise, not accurate   Accurate and precise

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!

1.3 Sig Figs in Calculations

Multiplication and Division:
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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$$\text{Percent uncertainty} = \frac{\delta A}{A} \times 100\%$$

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The bag weighs 5 lb $\pm 8\%$

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

Key Equations

$$v_{\text{avg}} = \frac{d}{t} \tag{1}$$

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

Complete the assigned problems

posted on the LMS

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