

# CALCULUS-BASED PHYSICS-2: ELECTRICITY, MAGNETISM, AND THERMODYNAMICS (PHYS180-02): UNIT 0

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3. Syllabus: Moodle (will examine shortly)
4. Office hours: Mondays, 8:00-10:00
5. PHYS150 or PHYS135A and MATH141B (concurrent)
6. Text: University Physics Volume 2 ([openstax.org](https://openstax.org))

## OPENING REMARKS - WELCOME!

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## FORCE AND MOTION CONCEPTUAL EVAL- UATION (FMCE)

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## SUMMARY

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*Physics - φυσική - "phusiké": knowledge of nature*  
from φύσις - "phúsis": *nature*

**Reading: Chapters 1 and 2 (for Unit 1)**

### 1. Estimation/Approximation

- **Estimating** the correct order of magnitude
- **Building** complex quantities
- **Unit analysis**

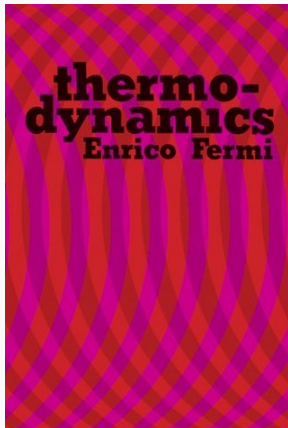
### 2. Review of concepts from Newtonian mechanics

- Kinematics and **Newton's Laws**
- Work-energy theorem, energy conservation
- Momentum, conservation of momentum

**Bonus Essay assignment:** If you submit a 10-page paper on the history of physics, including references from both online and library sources by the end of the semester, I will replace your lowest midterm score with the grade of the paper. Example topics:

- A paper on the Advanced LIGO experiment, and gravitational radiation (Nobel Prize 2017)
- Development of the idea of energy conservation versus caloric theory by James Joule and others
- Discovery of the charge to mass ratio of the electron by J.J. Thompson
- First description of the *photoelectric effect* by Albert Einstein

Before beginning the essay, please make an appointment with me in office hours so that we may agree upon a topic.



**Figure 1:** Less than 10 bucks on Amazon. Also, I have a copy. (May assign problems for advanced students).



## ESTIMATION/APPROXIMATION

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In science and engineering, **estimation** is to obtain a quantity in the absence of precision, informed by rational constraints.

1. Define relevant **scales**: mg, g, kg
2. Obtain **complex quantities** from simple ones
  - Obtain *areas* and *volumes* from *lengths*
  - Obtain *rates* from *numerators* and *denominators*
3. Constrain the unknown with **upper** and **lower** limits
4. Scaling problems: how does a complex quantity depend on other quantities?

## ESTIMATION/APPROXIMATION

### Choose a reasonable scale:

Estimate the mass of termites in a termite colony. Assume that the colony is a species known to have  $10^6$  individuals (roughly) per colony.

- A: 0.01 kg
- B: 0.1 kg
- C: 1 kg
- D: 10 kg

### Volume/density from other

**quantities:** An adult humpback whale is about 15 meters long. What is the mass of a baby humpback whale? (1 tonne = 1000 kg).

- A: 100 tonnes
- B: 50 tonnes
- C: 10 tonnes
- D: 2 tonnes

## ESTIMATION/APPROXIMATION

**Upper and lower bound:** The density of water is  $1000 \text{ kg/m}^3$ . What is the density of ice, approximately? (Don't think too hard!)

- A:  $550 \text{ kg/m}^3$
- B:  $920 \text{ kg/m}^3$
- C:  $1050 \text{ kg/m}^3$
- D:  $1200 \text{ kg/m}^3$

**Volumes from other quantities:** A jar at the coffee shop is filled with coffee beans, and a we can win a prize for guessing the number of beans. If the radius of the jar is about 4 cm, and the height is about 10 cm, how many beans are in the jar?

- A: 200
- B: 2,000
- C: 10,000
- D: Um, like, a million...

**Rates from other quantities:** A student travels from uptown Whittier to SLC in roughly 10 minutes. What is her average speed?

- A: 0.1 m/s
- B: 1 m/s
- C: 5 m/s
- D: 10 m/s

**Scale:** The distance between the Earth and the sun is 1 AU. What is the distance between the Sun and Venus?

- A: 10 million km
- B: 100 million km
- C: 0.2 AU
- D: 0.7 AU

**Scaling problem:** A type of rice grain, when cooked, doubles in length. By what factor does the volume of the grain increase?

- A: A factor of 2
- B: A factor of 4
- C: A factor of 8
- D: A factor of 10

**Scaling problem:** If the *temperature* of a gas remains constant, the *pressure* is inversely proportional to the volume of the gas. If the volume of a cylinder is decreased by a factor of three, by what factor does the pressure change?

- A: 3
- B:  $1/3$
- C: 1
- D: 9

**Unit analysis:** Which of the following are top speeds of a runner at the end of a sprint?

- A:  $10 \text{ m/s}^2$
- B:  $30 \text{ kg m/s}$
- C:  $7 \text{ m/s}$
- D: 20 miles per hour

**Unit analysis:** Which of the following is the gravitational acceleration near the Earth's surface?

- A:  $9.8 \text{ m/s}$
- B:  $-9.8 \text{ m/s}$
- C:  $-9.8 \text{ m/s/s}$
- D:  $9.8 \text{ m/s/s}$

$$\vec{p} = 4\hat{i} + 2\hat{j}, \vec{q} = -4\hat{i} + 2\hat{j}.$$

Compute  $\vec{p} + \vec{q}$ .

- A:  $4\hat{i} + 4\hat{j}$
- B:  $0\hat{i} + 4\hat{j}$
- C:  $4\hat{i} + 0\hat{j}$
- D: 0

$$\vec{p} = -1\hat{i} + 6\hat{j}, \vec{q} = 3\hat{i} + 0.5\hat{j}.$$

Compute  $\vec{p} \cdot \vec{q}$ .

- A: -1
- B: 1
- C: 0
- D: 3



## KINEMATICS AND NEWTON'S LAWS

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*Kinematics* - A **description** of the motion of particles and systems

*Dynamics* - An **explanation** of the motion of particles and systems

What causes an object to move? **Forces**. Forces exist as a result of the **interactions** of objects or systems.

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*Evolution* - A **description** of the change of biological species

*Natural Selection* - An **explanation** of change in biological species

What causes species to evolve? **Natural selection**. Natural selection exists because of **election pressures**, **numerous offspring**, and **variation** among offspring.

**Newton's First Law:** A man slides a palette crate across a concrete floor of his shop. He exerts a force of 60.0 N, and the box has a constant velocity of 0.5 m/s. What force cancels his pushing force, and what is the value in Newtons?

- A: wind, 60.0 N
- B: friction: 60.0 N
- C: friction: -60.0 N
- D: weight: -60.0 N

**Newton's Second Law:** The crate has a mass of 50 kg, and encounters an area where there is no longer friction. If the pushing force is still 60 N, what is the acceleration?

- A: 1.0 m/s/s
- B: 0.8 m/s
- C: 1.2 m/s
- D: 1.2 m/s/s

**Kinematics:** If the acceleration is  $1.2 \text{ m/s/s}$ , and the crate begins with a velocity of  $1 \text{ m/s}$ , what is the velocity after 5 seconds?

- A:  $4 \text{ m/s}$
- B:  $5 \text{ m/s}$
- C:  $6 \text{ m/s}$
- D:  $7 \text{ m/s}$

**Newton's Third Law:** Suppose the frictionless area continues indefinitely, and the velocity reaches 7 m/s. What will be the velocity if the pushing force decreases to 0 N, when the crate has traveled 10 m?

- A: 7 m/s
- B: 8 m/s
- C: 9 m/s
- D: 10 m/s

# WORK-ENERGY THEOREM AND CONSERVATION OF ENERGY

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### Physical Definition of Work

Let  $\vec{F}$  be a force exerted on a system, which is displaced by a displacement  $\vec{x}$ . The **work** done on the system is

$$W = \vec{F} \cdot \vec{x}$$

The units of work are  $\text{N m} = \text{kg m/s}^2$ , or *Joules*.



Let  $\theta$  be the angle between the force and the displacement.  
Then this equation

$$W = \vec{F} \cdot \vec{x} \quad (1)$$

becomes

$$W = Fx \cos \theta \quad (2)$$

What about Newton's 3rd Law? If one system  $A$  exerts a force  $F_{AB}$  on a system  $B$ , then Newton's 3rd law states that system  $B$  exerts a force  $-F_{AB}$  on system  $A$ .

If the work done by  $A$  on  $B$  is  $W = (F_{AB})x \cos \theta$ , then the work done by  $B$  on  $A$  is  $W = -(F_{AB})x \cos \theta$ .

What if the force varies over the trajectory of the system? We simply have to add up each contribution along the trajectory:

$$W = \int_{AB} \vec{F} \cdot d\vec{r} \quad (3)$$

## WORK AND REVERSIBLE PROCESSES: THE EXAMPLE OF FRICTION

In the first semester we encountered *irreversible* processes: energy lost to *friction*, and energy lost to *drag*. The irreversible process is a deeper notion in thermal physics, because it leads to the Second Law of Thermodynamics.

**Group board exercise:** Suppose a system moves at constant speed along a rough surface. Draw two closed, two-dimensional paths, each describing the trajectory of the system. A closed path means the system has a final displacement of zero. Recall that the frictional force is not conservative. Which path requires more work? **Key question:** If the speed is constant the entire time, and one path requires more work than the other, what happens to the excess energy (*they have the same final kinetic energy*)?

## KINETIC ENERGY AND THE WORK-ENERGY THEOREM

The formal proof involves combining **Newton's Second Law**, and the **Definition of Work**. Let the *kinetic energy* of a particle be defined by the mass and velocity of the particle, such that  $KE = \frac{1}{2}mv^2$ . Consider that

$$W = \int_{AB} \vec{F} \cdot d\vec{x} \quad (4)$$

$$W = \int_{AB} (m\vec{a}) \cdot d\vec{x} \quad (5)$$

$$W = m \int_{AB} \left( \frac{d\vec{v}}{dt} \right) \cdot d\vec{x} \quad (6)$$

$$W = m \int_{AB} \vec{v} \cdot d\vec{v} \quad (7)$$

$$W = \frac{1}{2}mv_B^2 - \frac{1}{2}mv_A^2 = \Delta KE \quad (8)$$

$$W = \Delta KE \quad (9)$$

**Group board exercise:** A firework of mass  $1\text{ kg}$  is launched straight upwards. The gunpowder releases  $500\text{ J}$  of energy. What is the velocity of the shell as it leaves the launcher? How high does it fly straight upwards?

**Group board exercise:** A slingshot is like a spring with a spring constant of  $2000 \text{ N/m}$ . If a projectile is placed in the slingshot pouch, how much work is required to draw it back  $10 \text{ cm}$ ?

*Actually, we learned last semester from our group projects that rubber doesn't always provide a **linear** restoring force.*

**Group board exercise:** If the pouch is released, what is the final velocity of the projectile if all of the work is converted into kinetic energy?



Momentum is defined as follows:

### Definition of Momentum

A particle of mass  $m$  and velocity  $\vec{v}$  has the vector *momentum*:

$$\vec{p} = m\vec{v}$$

There is a corollary:

Newton's Second Law with momentum

If a particle has acceleration  $\vec{a} = \frac{d\vec{v}}{dt}$ , then

$$\vec{F}_{\text{Net}} = \frac{d\vec{p}}{dt}$$

## DEFINITION OF MOMENTUM

An object that has a small mass and an object that has a large mass have the same momentum. Which mass has the largest kinetic energy?

- A: The one with the small mass
- B: The one with the large mass
- C: If the momentum is the same the kinetic energy is the same
- D: Cannot determine the answer

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Last semester we went into detail **classifying collisions**. For our purposes this semester, we just need to remember that collisions come in two basic forms:

- *Elastic type*: **Both** kinetic energy and momentum are conserved.
- *Inelastic type*: Momentum is conserved.

A puff of dust is composed of  $10^6$  dust particles, each with mass of  $1\mu\text{g}$  (microgram), or  $10^{-6}$  grams. The average velocity of each particle is 1 m/s. What is the total kinetic energy, adding up the contributions from all the particles?

- A:  $\frac{1}{2}$  mJ, or a millijoule (0.001 Joules)
- B:  $\frac{1}{2}$   $\mu\text{J}$ , or a microjoule ( $10^{-6}$  Joules)
- C: 1 millijoule
- D: 1 Joule

What is the mass of the puff of dust, if it has  $10^6$  particles each with a mass of 1 microgram?

- A: 1 kilogram
- B: 1 milligram
- C: 1 gram
- D: 1  $\mu\text{g}$

Which condition will cause this number to change?

- A: The temperature of the puff is increased.
- B: All of the collisions were somehow inelastic.
- C: All of the collisions were somehow elastic.
- D: Dust particles were removed from the puff.



Which condition will cause the *temperature* of the dust cloud to change? (Think conceptually, from your intuition).

- A: The average speed of the particles increases.
- B: The collisions are all inelastic; kinetic energy of the particles decreases on average.
- C: The collisions are all elastic; the kinetic energy of the particles stays constant.
- D: Dust particles were removed from the puff.

Which condition will cause the *temperature* of the dust cloud to change? (Think conceptually, from your intuition).

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So which parts of Newtonian mechanics are we going to need to understand thermal physics? (Heat, temperature, energy transfer).

- Newton's laws, momentum and kinetics → motions of molecules in gases → temperature and heat
- Work and energy → work done by thermal systems → energy conservation with heat
- Irreversible processes → energy dissipation → entropy

## CONCLUSION

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*Physics* - φυσική - "phusiké": *knowledge of nature*  
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## ANSWERS

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## ANSWERS

- 1 kg
- 2 tonnes
- 2,000
- 1 m/s
- 100 million km or 0.7 AU
- A factor of 8
- 3
- C and D
- $-9.8 \text{ m/s/s}$
- $0\hat{i} + 4\hat{j}$
- 0
- friction:  $-60.0 \text{ N}$
- $1.2 \text{ m/s/s}$
- $7 \text{ m/s}$
- $7 \text{ m/s}$
- The one with the small mass
- The one with the large mass
- $\frac{1}{2} \text{ mJ}$ , or a millijoule (0.001 Joules)
- 1 gram
- Dust particles were removed from the puff.

- A and B

- ...