Centering Units on Biologically and Chemically Authentic Motivating Contexts in a Large-Enrollment IPLS-II Course

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What is a *motivating context*?

An authentically interdisciplinary problem (biological or chemical in our case), towards which a unit builds. The context is introduced early and referred to often in the unit.

Biology vs. physics epistemology: “Biology faculty prefer to discuss real specific systems – cells, organisms, ecosystems – and most examples require appreciating a great deal of realistic detail, even in introductory classes.”

- E.F. Redish et al, Am. J. Phys. 82, 368 (2014).

Essential questions: as “open-ended,” “thought provoking and intellectually engaging,” which “recur over time” and “call for higher-order thinking”

- J. McTighe and G. Wiggins, *Essential Questions: Opening Doors to Student Understanding* (ASCD, 2013).

“examples in which fundamental physics contributes significantly to understanding a biological system to make explicit the value of physics to the life sciences. This requires selecting the course content to reflect the topics most relevant to biology while maintaining the fundamental disciplinary structure of physics.”

- C.H. Crouch and K. Heller, American Journal of Physics **82**, 378 (2014).

What do we mean by *authenticity*?

*By biologically **authentic applications**, we mean those that use tools —such as concepts, equations, or physical tools —in ways and for purposes that reflect how the discipline of biology builds, organizes, and assesses knowledge about the world. We note that it is not only the perspective of the disciplinary expert that matters here; the student's perception of biological authenticity matters as well. When they perceive physics as valuable to their understanding of biology and chemistry, their engagement in-creases dramatically.*

E.F. Redish et al, Am. J. Phys. 82, 368 (2014).

34.33 • **BIO** **The Cornea As a Simple Lens.** The cornea behaves as a thin lens of focal length approximately 1.8 cm, although this varies a bit. The material of which it is made has an index of refraction of 1.38, and its front surface is convex, with a radius of curvature of 5.0 mm. (a) If this focal length is in air, what is the radius of curvature of the back side of the cornea? (b) The closest distance at which a typical person can focus on an object (called the near point) is about 25 cm, although this varies considerably with age. Where would the cornea focus the image of an 8.0-mm-tall object at the near point? (c) What is the height of the image in part (b)? Is this image real or virtual? Is it erect or inverted? (*Note:* The results obtained here are not strictly accurate because, on one side, the cornea has a fluid with a refractive index different from that of air.)

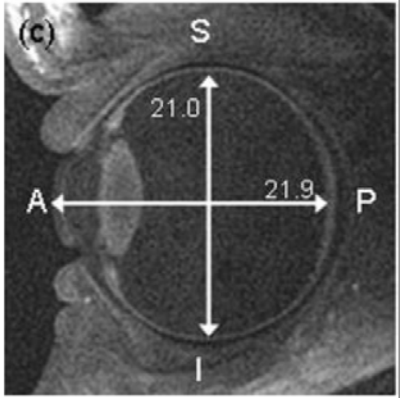
Hugh D. Young and Rodger A. Freedman, *Sears and Zemansky's University Physics with Modern Physics*, 13th ed. (Addison-Wesley, San Fransisco, 2012). pp. 1156.

You Try – Farsightedness (hyperopia)

Last time, you determined the focal length of a "perfect" eye was 21.9mm. This is for the eye at rest and looking infinitely far away.

a) For someone with "perfect" vision, the closest they can see (the *near point*) is about 250mm (25cm). What focal length of the eye is needed to see this distance if the eye is 21.9mm across? This is the shortest focal length your eye can attain.

b) What if your eye was only 21.1mm across?
   i. Where would the image be, relative to the retina, at an object distance of 250mm?
   ii. Assuming a constant shortest focal length (reasonable given that this is set by the cornea and lens), how far out would you need to be to be able to see?



[1] Updated information used throughout these slides from: Atchison, D.A., Jones, C.E., Schmid, K.L., Pritchard, N., Pope, J.M., Strugnell, W.E., and Riley, R.A. (2004). Eye Shape in Emmetropia and Myopia. Invest. Ophthalmol. Vis. Sci. 45, 3380–3386.

- To the course as a whole.
- An example unit on quantum mechanics

NOW, LET’S SEE THIS APPLIED TO AN IPLS – II COURSE AT UMASS AMHERST

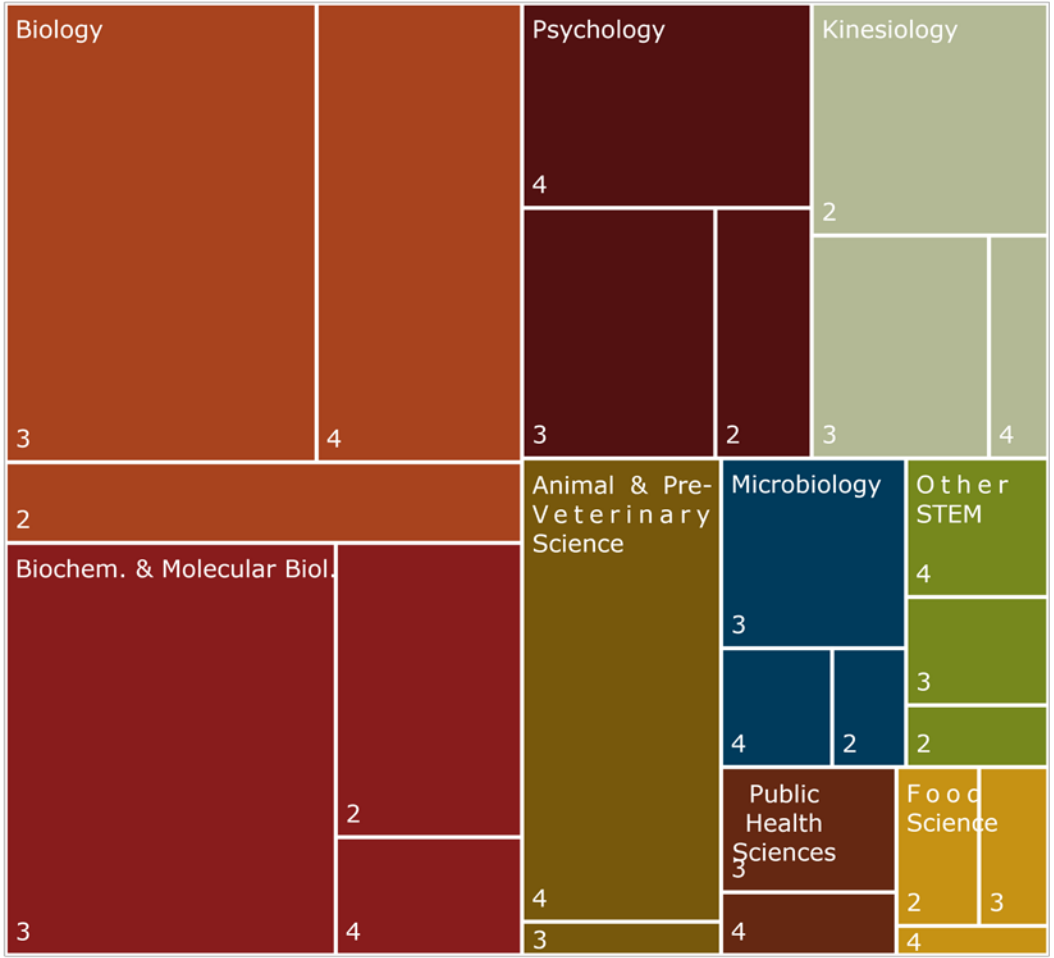
Before we begin: context

Second semester in an IPLS sequence

Basic stats:
- 2x300
- 1 instructor
- 2 GTAs
- 4 UTAs
- Lab handled separately.

Teams:
- Opt-in teams of 4-5
  - Requested by students
  - Biggest logistically possible both in room and remotely
- 65-75% of students join
- Teams set attendance policy
- CATME for team formation and peer evaluation

Student Demographics – Major and Year

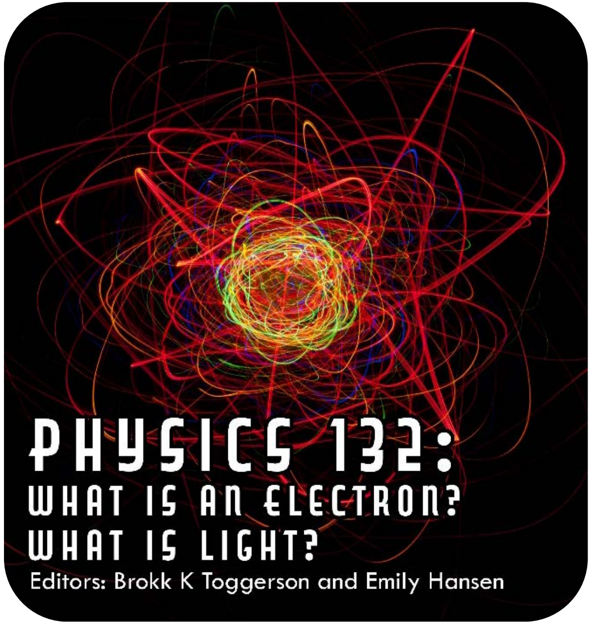


Albert C. Kowitz and Thomas J. Knutson, *Decision Making in Small Groups: The Search for Alternatives* (Allyn and Bacon, Inc., Boston, MA, 1980).

Course as a whole

Official Description

Basic principles of physics illustrated by example and demonstration, whenever possible, from the biological sciences, with lab. Topics: electricity, magnetism, radiation, optics, quantum theory, atomic structure, nuclear physics.



What concept(s), which *my students will see* as relevant, connect these ideas?

"I've got to see how physics is related to our life. As a biochemistry major, I've been learning about electrons and light a lot, but I didn't get to fully understand those. It was really fascinating to learn how everything works in a way it does, and I made a lot of connections with this physics concepts with other disciplines."

What is an electron? What is light? Essential Questions → Topics

Basic principles of physics illustrated by example and demonstration, whenever possible, from the biological sciences, with lab. Topics: electricity, magnetism, radiation, optics, quantum theory, atomic structure, nuclear physics.

What is the fundamental nature of light and electrons?

- Quantum theory.
- Atomic structure.

How do changes in material impact the motion of light and electrons?

- Geometric optics.

How does having charge impact electron behavior?

- Electric fields.
- Electric potential.

What is the impact of many electrons moving together?

- Circuits.

When we say that light is a wave, what is doing the waving?

- Magnetism.
- Electrodynamics.

Developing motivating contexts

What is the fundamental nature of light and electrons?
- Quantum theory.
- Atomic structure.

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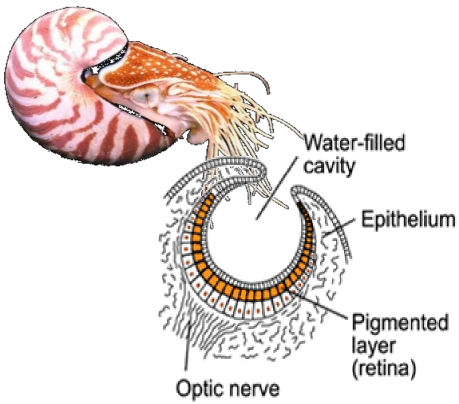
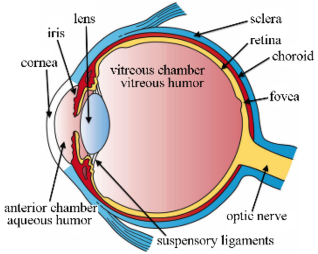
When we say that light is a wave, what is doing the waving?
- Magnetism.
- Electrodynamics.

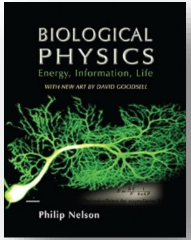
- Some are obvious





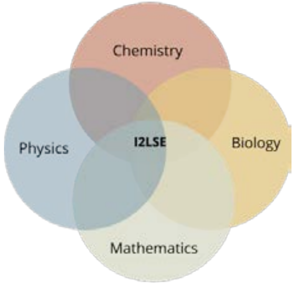
- Others… a little more complex (particularly for an ex-particle physicist ☺)
- Even the obvious ones, a lot of research is required to achieve authenticity.
  - Want the language and values to be correct!

Developing motivating contexts



Textbooks on biophysics

Integrated Introductory Life Science Education Group (I^2LSE)



On-the-ground lecturers from:

- Calculus for Life-Science I
- Introductory Biology I
- General Chemistry I
- Organic Chemistry II
- IPLS I & II

Going week-by-week through the material.

- Helps see the exact content.
- Explain it to each other.
- Look for connections.
- Align material so that the order makes sense.
  - E.g. do acids in bases in Chemistry before they get to the content in Biology.

Understand differences in disciplinary language and variables.

- Variables
  - Math: uses the same set x, y, z, t, a, b, c and tends to avoid subscripts.
  - Chemistry and Physics: love our subscripts!
- E.g. 1st Law of Thermodynamics:
  - Physics is typically the work done by the system: $\Delta E = Q - W$.
  - Chemistry is interested in the work done *on* the system → $\Delta E = Q + W$.
- C – C = C bond
  - Physics: a delocalized electron
  - Chemistry: a conjugated π-bond

Understand differences in *values*.

- A physics toy model may be off 20% and we consider that "pretty good." Biologists recoil at that (such a difference turns a carrot from orange to violet!).
- Chemistry texts tend to have formulas for hydrogen spectra and photoelectric effect. Physicists, see them as applications of conservation of energy.

Watch each other teach.

- See how the principles are used in class.
- Learn new techniques for teaching large courses.

My motivating contexts:

What is the fundamental nature of light and electrons?

Why does chemistry work?
We know electrons in atoms exist in discrete energy levels, why?
Can we predict the molecular orbital shapes and transitions for some long carbon chains?

How do changes in material impact the motion of light and electrons?

How did the eye evolve? How do eyes earlier in evolutionary history work?
How does the human eye work?
How do classes correct vision?

How does having charge impact electron behavior?

How does the presence of a surrounding material impact electrical forces?
Gel electrophoresis and membrane potentials: both of these biological concepts center around the idea of “voltage.”
What is “voltage?”
How voltage related to the ideas of force and energy we discussed in 131?

What is the impact of many electrons moving together?

The neuron: how can we model it as an electrical circuit?
What can we learn about the biology by looking at a neuron from this perspective?

When we say that light is a wave, what is doing the waving?

Using the flipped model with motivating contexts

Reading
- Introduces the biology or chemistry using the native language.

Homework
- Explicit problems on the biology or chemistry to help ensure equity.

Class Problems
- "Traditional physics" type problems still used
- Frequent references to how the ideas can be applied to our motivating context.
- Ultimately conclude with our context.

Exam
- Among the traditional problems, includes questions directly related to the motivating context.

Example Application I – Quantum Mechanics

WHY DOES CHEMISTRY WORK?

WE KNOW ELECTRONS IN ATOMS EXIST IN DISCRETE ENERGY LEVELS, WHY?

CAN WE PREDICT THE MOLECULAR ORBITAL SHAPES AND HOMO TO LUMO TRANSITIONS FOR SOME LONG CARBON CHAINS?

How do we start? Readings in custom free and open web-book

Reviews calculating emission lines from hydrogen

http://openbooks.library.umass.edu/toggerson-132/

Thinking about Atomic Transitions from a Physics Perspective

In chemistry, the starting point for the analysis was generally

$$\Delta E = \frac{hc}{\lambda}$$

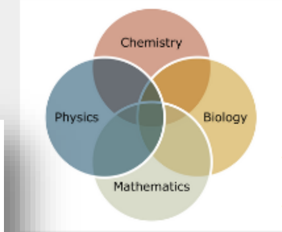
or if, you were looking at the hydrogen atom specifically,

$$\Delta E = -Rhc\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right).$$

Moreover, when solving the problem, you would probably just consider the absolute value of the change in energy and then figure out emission or absorption.

How would we look at this same problem in physics? In physics, we like to start with fundamental principles of the Universe and then apply definitions as described in Unit I On-A-Page: Principles and Definitions. In this case, the fundamental principle is Conservation of Energy: $\Delta E = Q + W$; this basic idea will, therefore be our starting point. To see how this works in practice, let's look at an example, the $n = 6 \rightarrow n = 2$ transition discussed in the video.

8. Review from Chemistry of Application of Conservation of Energy to Photons and Atoms



In your general chemistry courses, you already did some of what will be a big part of this unit: namely using the ideas of wave-particle duality in conjunction with conservation of energy. In chemistry, you did this in the context of looking at atomic transitions. In this chapter, you will review the ideas from chemistry, and then be exposed to some differences in how we will treat this same situation in a physics course. The reasons for the differences are three-fold. First, as described elsewhere in this book, each scientific discipline grew with its own history and conventions. The second reason for a different perspective is that the view taken by chemistry, while perfectly fine for all situations you encountered in that course, will break down for some of the situations we want to analyze in this course. The third, and arguably most important reason, mirrors the motivation for a variety of cultural perspectives in a humanities course: by exploring the same processes from different perspectives you gain a deeper and more holistic understanding of the material. Just as your understanding of history is incomplete if you only consider white men, so your understanding of conservation of energy is incomplete if you only look at it from a biology, chemistry, or physics perspective.

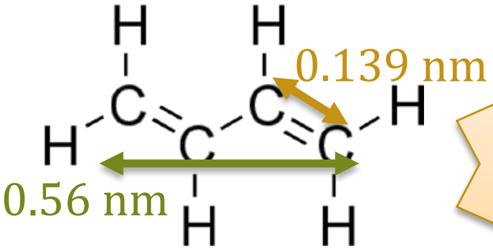
eview of Connecting Conservation of Energy to the ave and Particle Natures of Light in the Context of e Hydrogen Atom from Chemistry[1]

Thinking about Atomic Transitions from a Physics Perspective

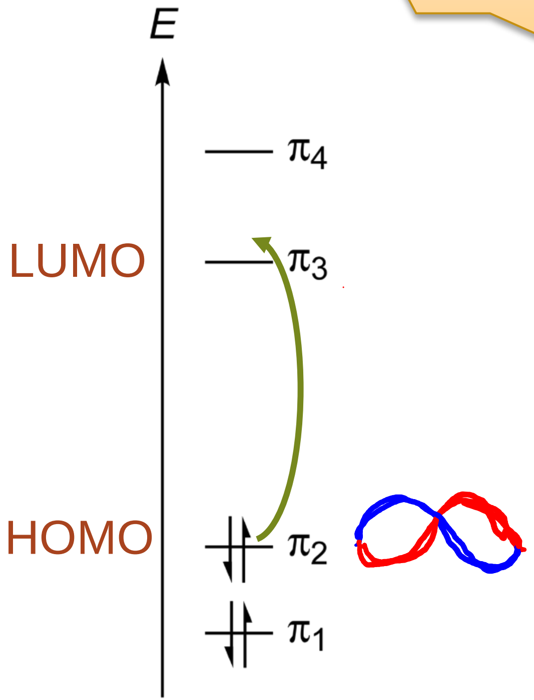
Taken directly from OpenStax Chemistry 2e for authenticity.

Ultimate Goal

- 1,3-butadine has 3 conjugated carbon-carbon bonds.
- There are four electrons in so-called π-bonds.
  - These electrons are *delocalized*
  - They are free to move the length of the C=C-C=C chain.
- **They are in a box!!!!**
  - C-C bond is $0.139\ \mathrm{nm}$
  - Electrons can go past the C's on the ends
  - Box is $L = 3(0.139\ \mathrm{nm}) + 0.139\ \mathrm{nm} = 0.56\ \mathrm{nm}$
- Since I can put two electrons in each state (spin-up and spin-down) $n = 1$ and $n = 2$ are populated
  - $n = 2$ is the HOMO (highest occupied molecular orbital)
  - $n = 3$ is the LUMO (lowest unoccupied molecular orbital)



1-3 butadine instead of usual β-carotene

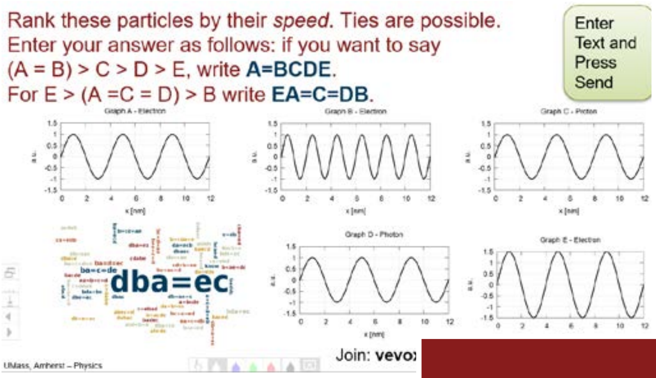


Questions

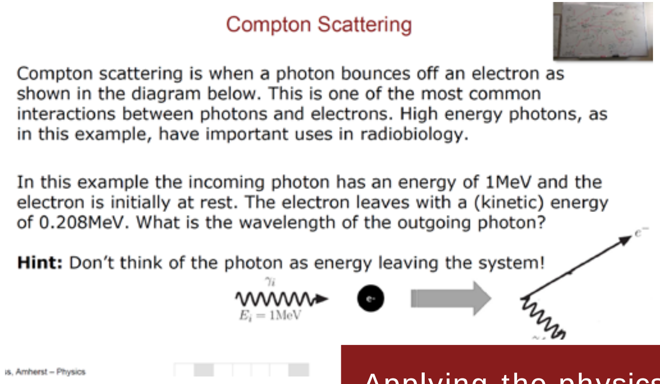
a) Draw molecular orbital for the HOMO.

b) What wavelength photons will be emitted as a HOMO electron jumps to the LUMO?

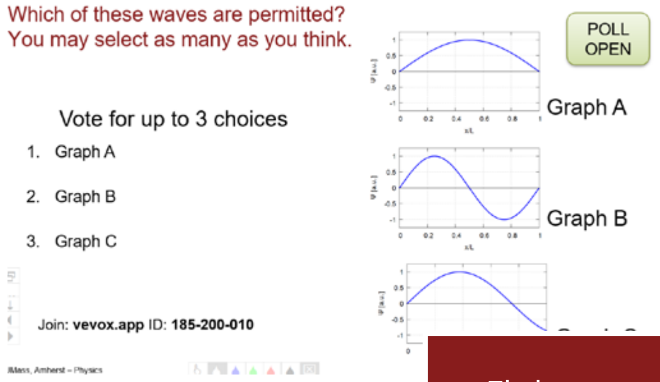
How do we get there? More traditional problems too!



Interpreting ψ



Applying the physics method of problem solving to new situations



Fitting waves in a box

SUMMARY

Authentic motivating contexts can be challenging to create, but are helpful to both students and instructors

Challenges

- Creating disciplinarily authentic examples requires that the instructor gain some mastery of the material.
  - Not just the facts.
  - Must also learn some of the
    - *Language*
    - *Conventions*
    - *Values*
- This is challenging without peer support.

Benefits

- Instructors
  - Help keeps focused on which topics to cover ← Doesn't help your context? Drop it!
  - Disciplinary diversity provides a natural segue into discussions on other forms of diversity and inclusion.
- Students
  - Get a chance to be the experts in the classroom.
  - Feel more connected to the material.

Anecdotal Support for Student Buy-In

Quotes from an end-of-semester survey: “What are the three most valuable things you learned in this course?”

- “How interconnected and important physics is- physics used to be seemingly useless to me as a biology major, but after this course, the way in which is was modeled taught me how it is impossible to study biology without seeing the physics behind the natural world”
- “Optics!!! Doing prescriptions was awesome.”
- “Learning about the ‘particle in a box’ idea was very valuable to me because I never really understood the ‘HOMO’ and ‘LUMO’ concepts concerning electrons in an atom.”
- “I learned how connected all science courses really are. We touched upon not only chemistry and biology, but into the specifics of how things like dipoles and electrophoresis really work.”
- “About neurons! I have always had trouble with neurons and through physics eyes it makes more sense now.”

THANK YOU

Backup:

Example Application II – Circuits

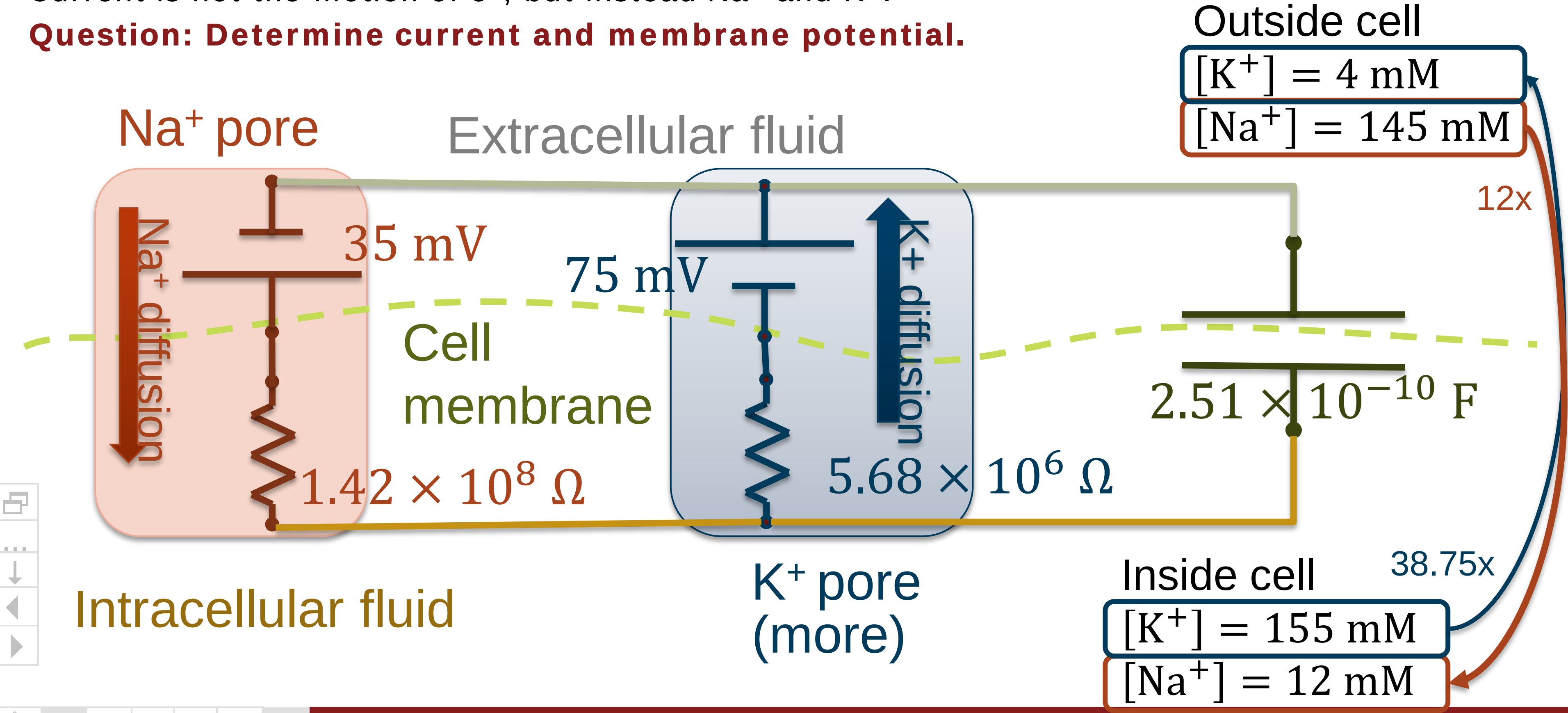
THE NEURON: HOW CAN WE MODEL IT AS AN ELECTRICAL CIRCUIT?

WHAT CAN WE LEARN ABOUT THE BIOLOGY BY LOOKING AT A NEURON FROM THIS PERSPECTIVE?

Our ultimate goal

A cell can be modelled by the circuit shown.
Current is not the motion of e-, but instead Na^+ and K^+.

Question: Determine current and membrane potential.



How we get there – Reading and homework

24. Introduction and Motivating Biological Context for Unit IV

Introduction +

Motivating Biological Context for Unit IV – The Neuron –

In this unit, we will be looking at the neuron throughout. This section, from [OpenStax Biology – How Neurons Communicate](#) is to refresh your biology knowledge on these cells.

All functions performed by the nervous system—from a simple motor reflex to more advanced functions like making a memory or a decision—require neurons to communicate with one another. While humans use words and body language to communicate, neurons use electrical and chemical signals. Just like a person in a committee, one neuron usually receives and synthesizes messages from multiple other neurons before "making the decision" to send the message on to other neurons.

1. Start over

6 attempts remaining.

Which **TWO** ions are most important in understanding how neurons function electrically.

- ☐ **A.** OH^-
- ☐ **B.** Cl^-
- ☐ **C.** H^+
- ☐ **D.** K^+
- ☐ **E.** Na^+

Submit answer

During Class

- We are interested in a circuit that is neither simple series nor parallel.
- Skip the series and parallel combination formulae and jump to the more general Kirchhoff procedure.

The first problem *they* do in class