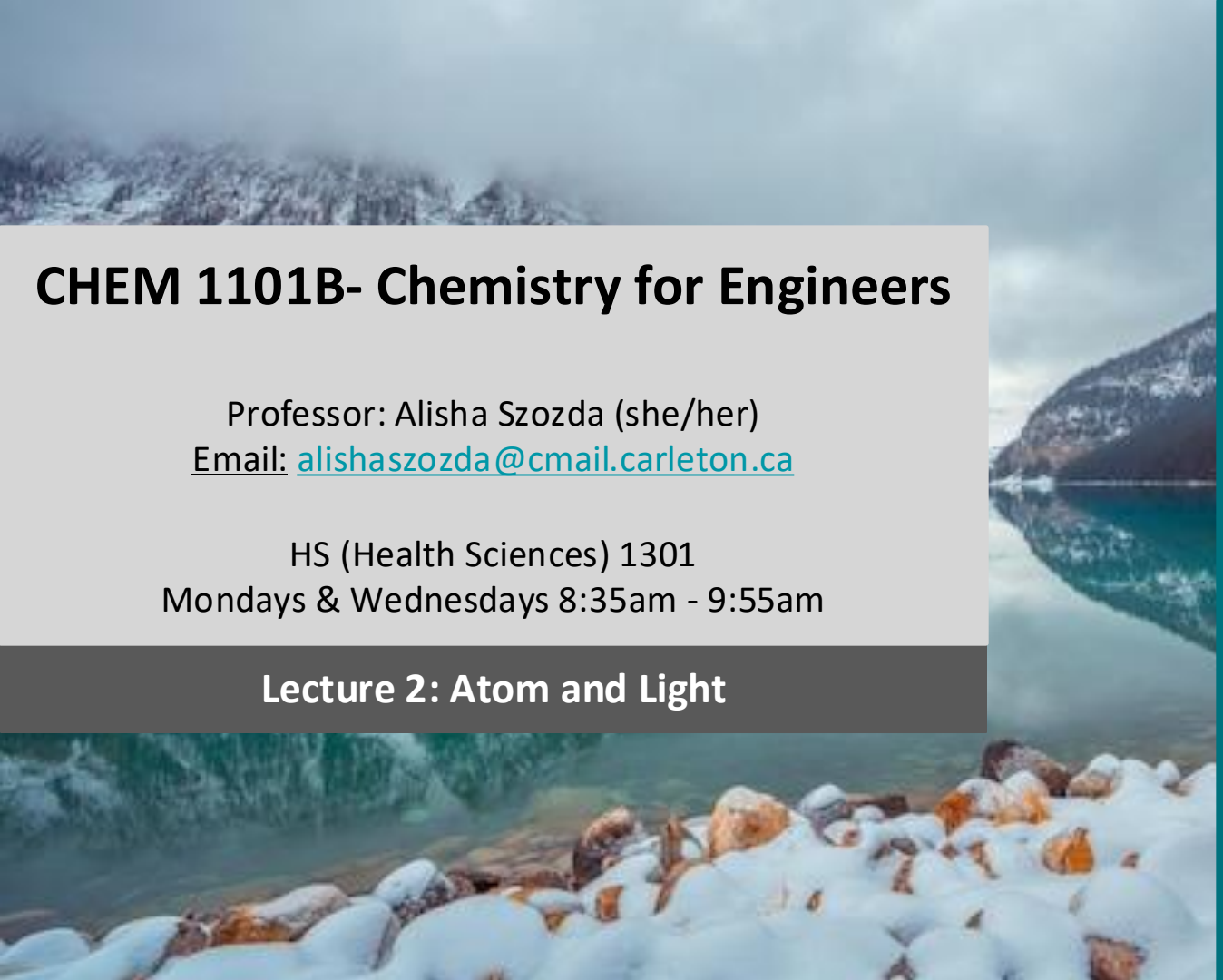

CHEM 1101B- Chemistry for Engineers

Professor: Alisha Szozda (she/her)
Email: alishaszozda@cmail.carleton.ca

HS (Health Sciences) 1301
Mondays & Wednesdays 8:35am - 9:55am

Lecture 2: Atom and Light

Welcome to the course!

Please feel free to introduce yourself to your neighbors– name, pronouns, a hobby, etc.

and/or

Complete Metacognitive assessment on Brightspace if you haven't completed it yet

Review: Logarithms ($\log_{10}$ & ln)

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Taking log or ln:

- **number of decimal places** in the calculated log or ln equals the **number of sig figs** in the original value (don't count digits left of decimal place).

Taking the anti-log:

- **number of sig figs after the decimal place** represents the **total number of sig figs** in the calculated result.

$$\ln(2.634\ x\ 10^{-19}) =$$

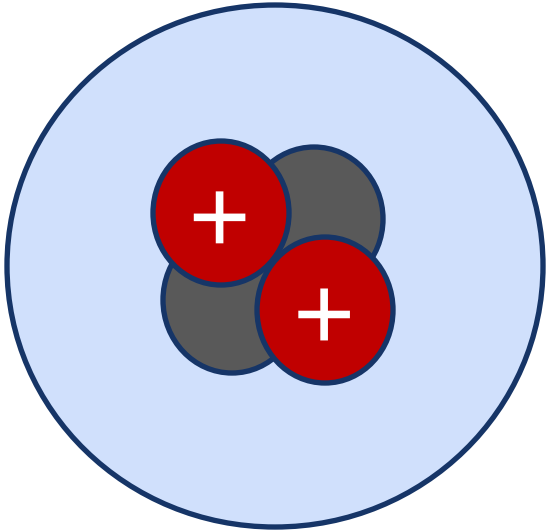
$$\log_{10}(x) = -8.000$$

$$x =$$

Review: Multiple Operations

$$ln(\mathrm{x}) = \frac{38.6\ x10^{3}}{8.814}\left(\frac{1}{373.2} - \frac{1}{464}\right); x = ?$$

Review: What defines an atom?

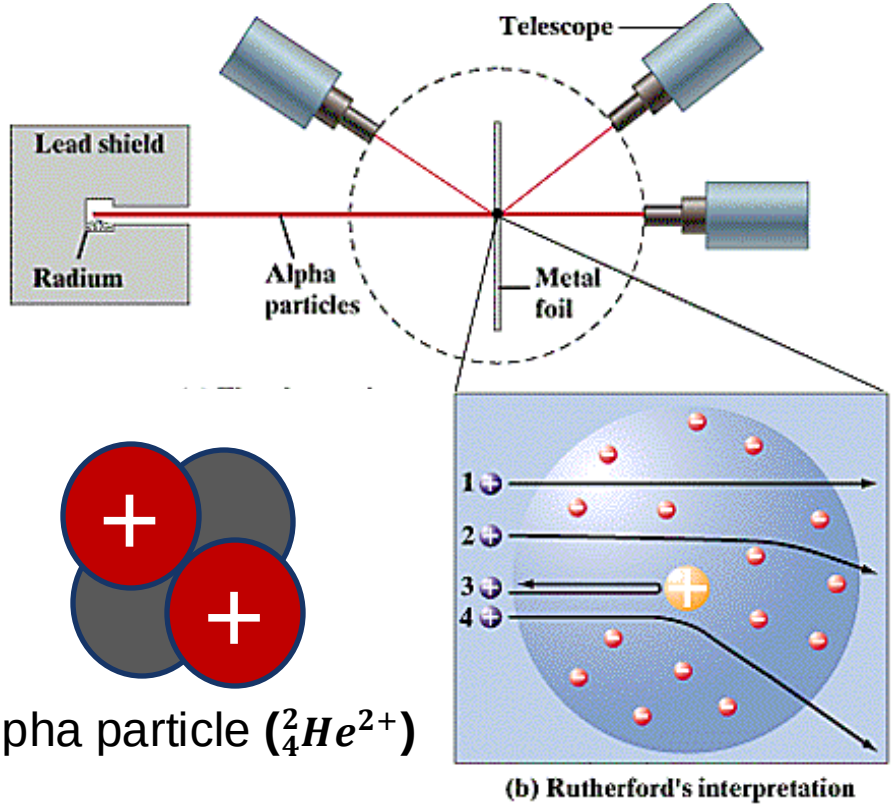


- All atoms are comprised of a dense nucleus filled with **neutrons (n^0) and protons (p^+)**, surrounded by a cloud of **electrons (e^-)**.

- Nucleons (**protons and neutrons**) have a mass of approximately 1 atomic mass unit (AMU), while **electrons** have a mass roughly 0.05% that of a nucleon.
  - Mass of proton: 1.67262×10^{-27} kg $\approx$ 1 AMU
  - Mass of neutron: 1.674927×10^{-27} kg $\approx$ 1 AMU

- **Protons** have a positive charge, **neutrons** are neutral, and **electrons** are negatively charged.

Rutherford Experiment



Alpha particle ($_{4}^{2}He^{2+}$)

Rutherford's experiment elucidated the **core structure** of the atom. When a gold sheet is bombarded with a beam of **charged alpha particles**, some **pass through**, some are **deflected**, and some are fully **reflected.**

Because the alpha particle is **positively charged**, the interpretation is that there is **a large cluster of positive charge** at the centre of an atom: **a nucleus**.

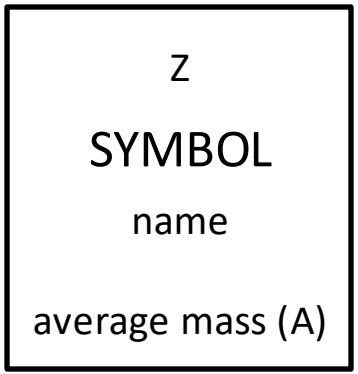
Review: The Atomic Symbol

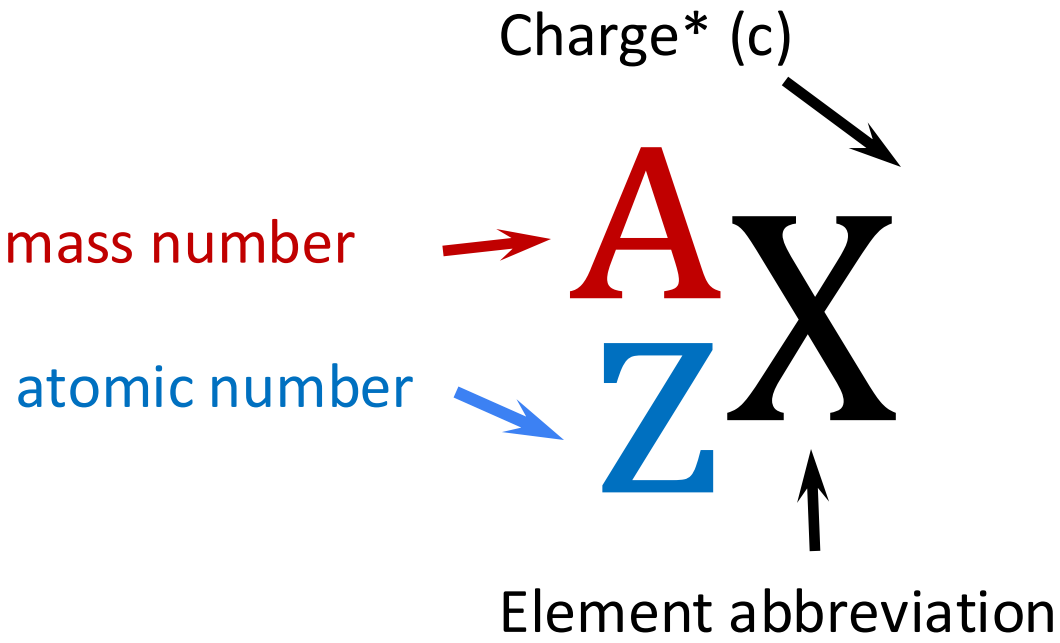
It is the number of protons in the nucleus that determines what kind of atom we have – what element it is

An atom is electrically neutral → equal number of protons and electrons

ATOMIC NUMBER (Z): the number of protons in the nucleus

MASS NUMBER (A): the number of protons in the nucleus





$A = n_{protons} + n_{neutrons}$

$Z = n_{protons}$

$c = n_{protons} - n_{electrons}$

$n_{neutrons} = A - Z$

$n_{protons} = Z$

$n_{electrons} = Z - c$

Learning Check 1

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$^{2}_{1}H$

A = 2

Z = 1

c = 0

$n_{neutrons}$ =

$n_{protons}$ =

$n_{electrons}$ =

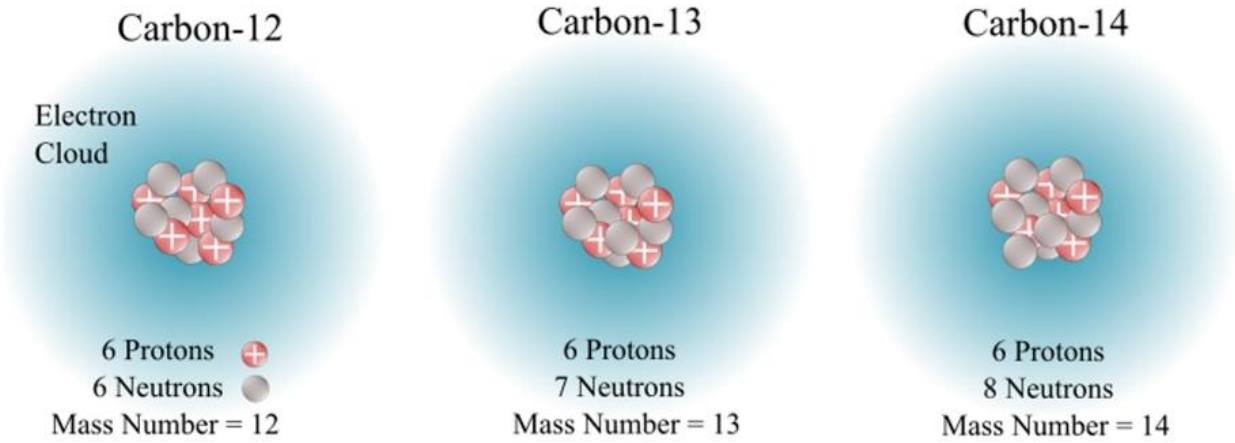
This is deuterium. It is often abbreviated as **D**. It is regularly used as a chemical tag in organic chemistry, as it behaves nearly identically to normal hydrogen (or **protium**).

Water when made with deuterium, is called "**heavy water**". Heavy water is used to cool down nuclear reactors, tastes vaguely sweet, and is potentially lethal when consumed in excess.

Review: Isotopes

Isotopes: Atoms of the same element (same Z) with different masses (A)

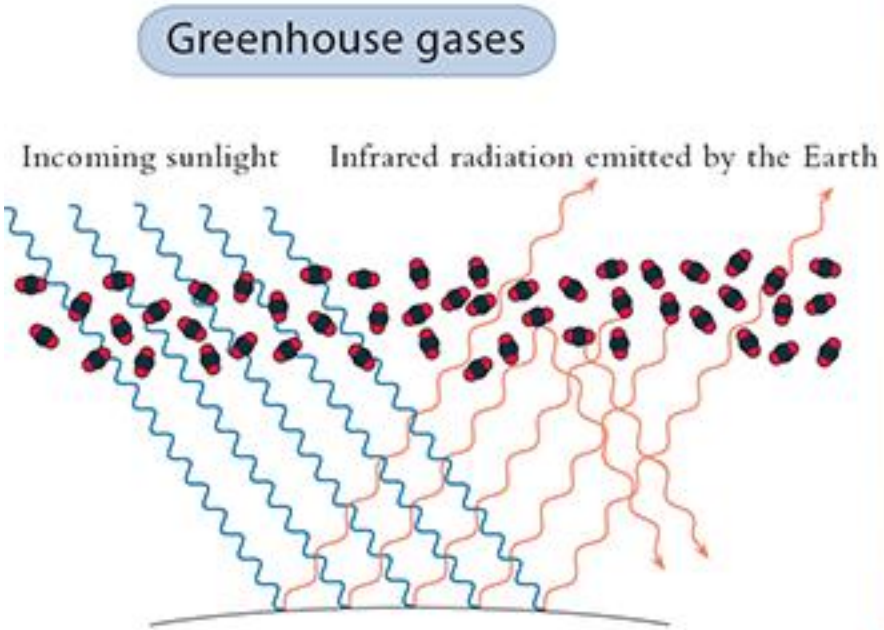
There are three isotopes of carbon found naturally, but only two are found in any significant amount:

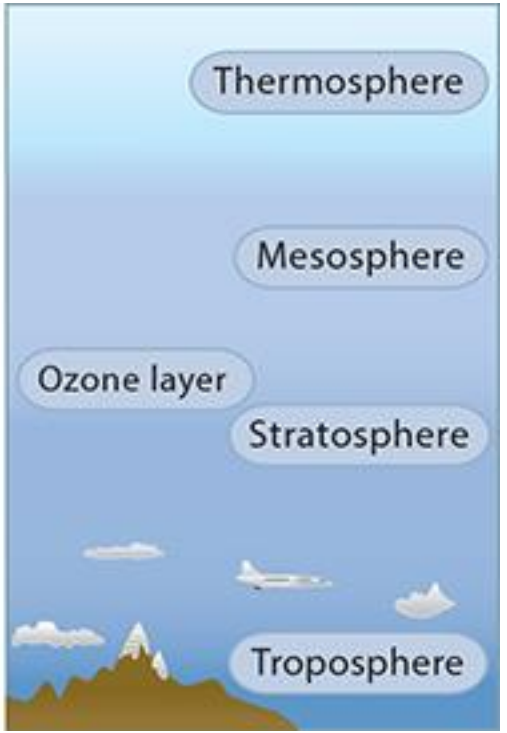


Learning outcomes Topic 2:
The ATOM – Rydberg and Photoelectric effect

- Relate the electromagnetic radiation emitted or absorbed to transitions between levels in the hydrogen atom
- Determine work functions and ionization energies given wavelength data from electromagnetic radiation and vice versa

Goal of this lesson: Apply chemical thinking to describe major chemical reactions in the stratosphere and explain the chemistry of the greenhouse effect.





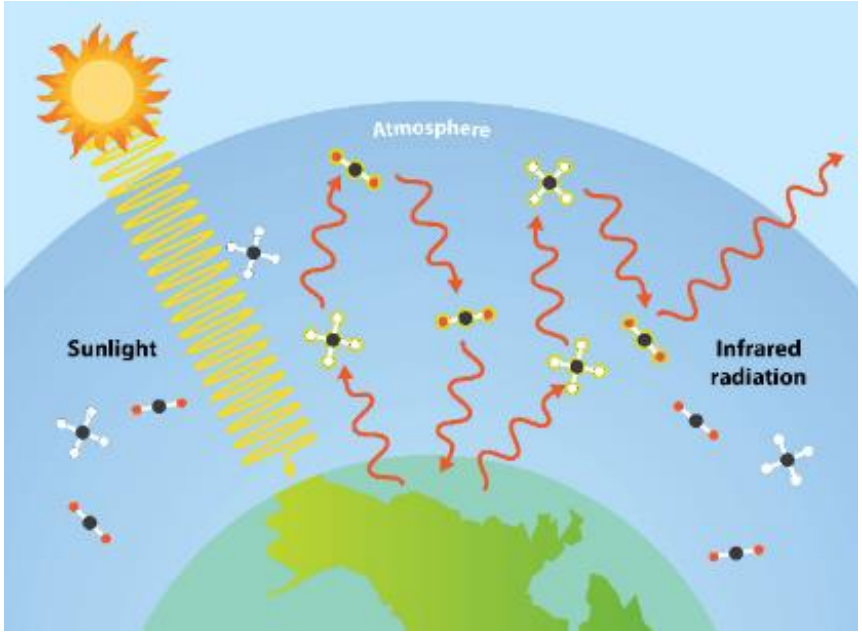
Focus Question!

Why and how do atmospheric components affect earth's atmosphere?

Light-Matter Interactions

Some atmospheric components interact with radiation emitted by the Sun and our planet. Those interactions result in energy exchanges that affect Earth's temperature.

What molecular properties determine these light-matter interactions?

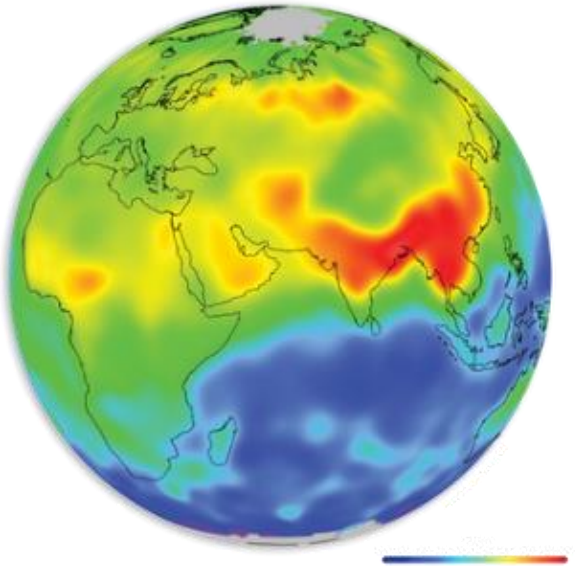


A Natural Phenomenon

Earth's atmosphere normally traps 84% of the solar energy re-emitted by the planet's surface. This phenomenon is called "greenhouse effect" and helps to keep an average temperature of 15 ^{o}C.

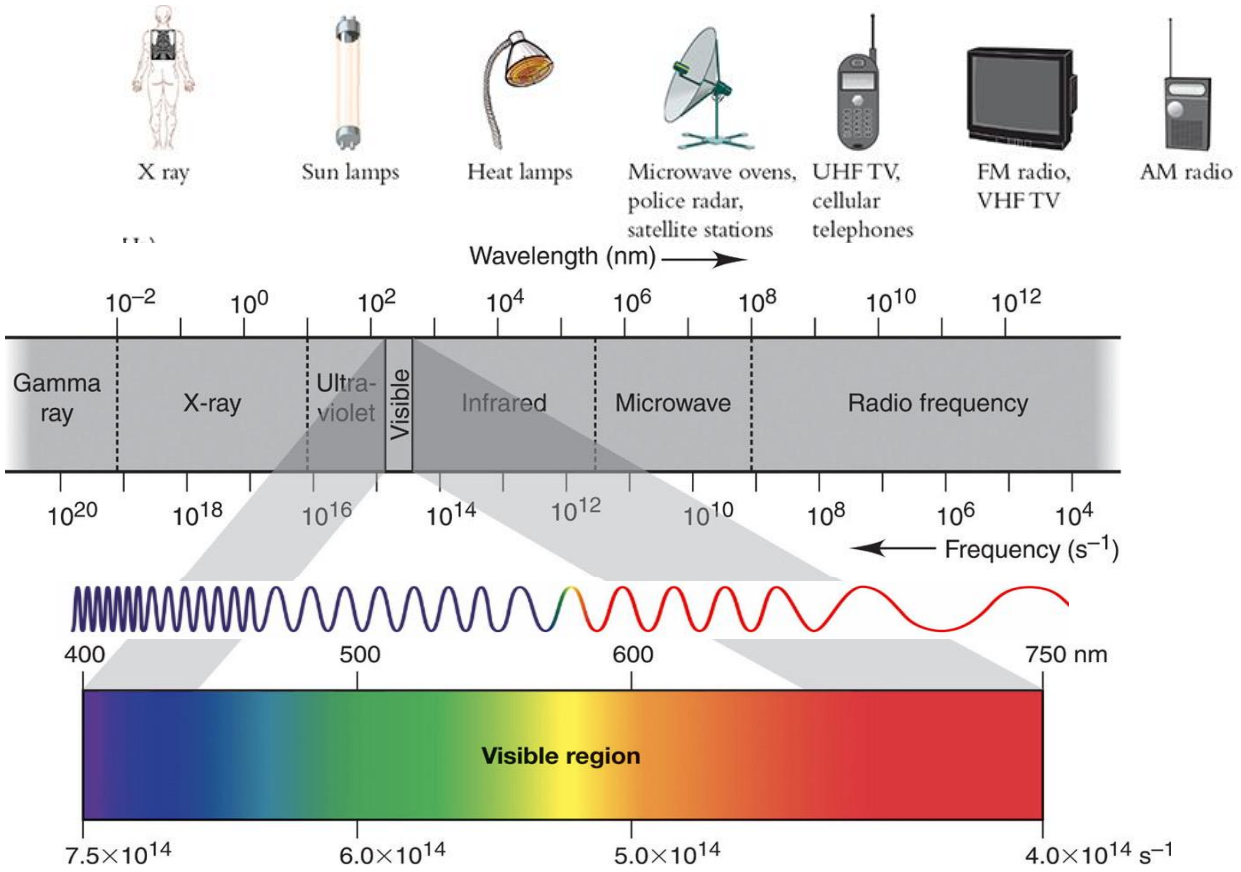
Without this effect, Earth would be below freezing

Earth's greenhouse effect is getting stronger as we add greenhouse gases to the atmosphere – warming the climate of our planet



So how does the greenhouse effect work?

Electromagnetic Radiation (EMR)



The sun emits EMR of different types.

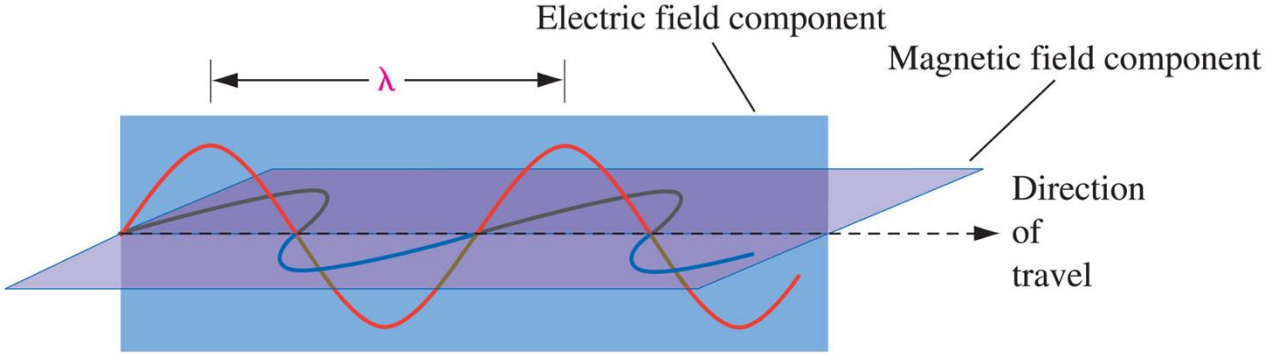
The sunlight that reaches the Earth's surface is in the ultraviolet, visible, and infrared regions.

This light interacts with atoms and molecules in the atmosphere.

Fundamental aspects of light: wave-like and particle-like

Light has 2 properties
- Wave-like
- Particle-like

To model EMR as waves or particles is an oversimplification, but for our purposes in studying the atom, thinking of EMR as made up of particles describes the phenomena relatively well, so we do it!



Photons: "particle" of light, whose energy depends on the frequency or wavelength of radiation

$c = \nu\lambda$

Frequency Wavelength

c = velocity of light = 2.998 x 10^8 m/s

The Photoelectric Effect

A phenomenon known as the photoelectric effect shows how the energy of light depends on its **frequency** and **intensity**

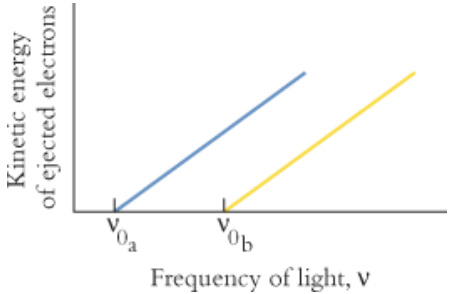
When a beam of photons of sufficient energy strikes a collection of atoms of any element, electrons are emitted from the atoms.

- The photoelectric effect involves the collision of ONE photon with ONE electron

$$E_{photon} = h \cdot \nu_{photon} = \frac{h \cdot c}{\lambda}$$

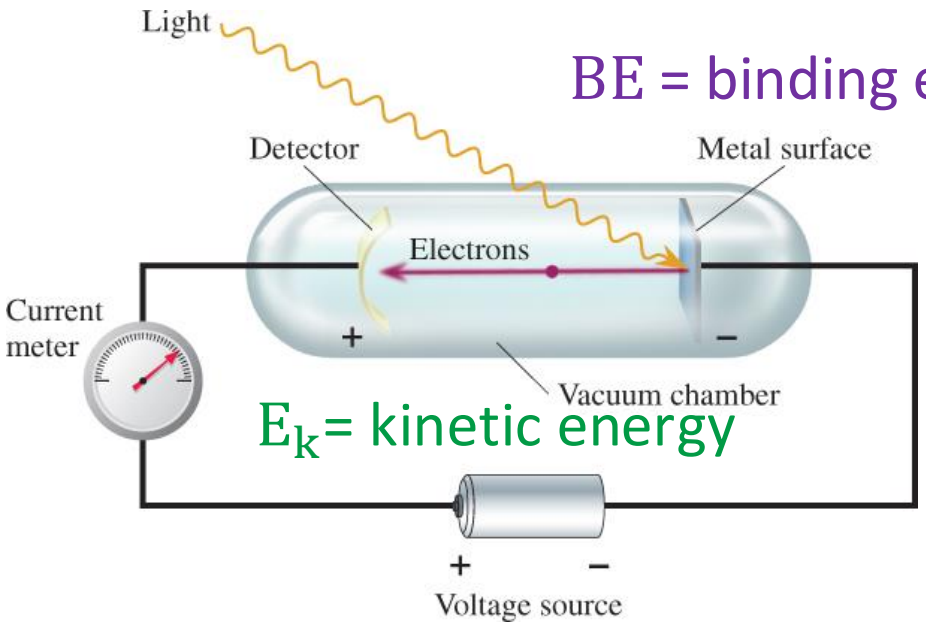
h = Planck's constant = 6.6262 x 10-34 J•s

What is the role of light intensity?



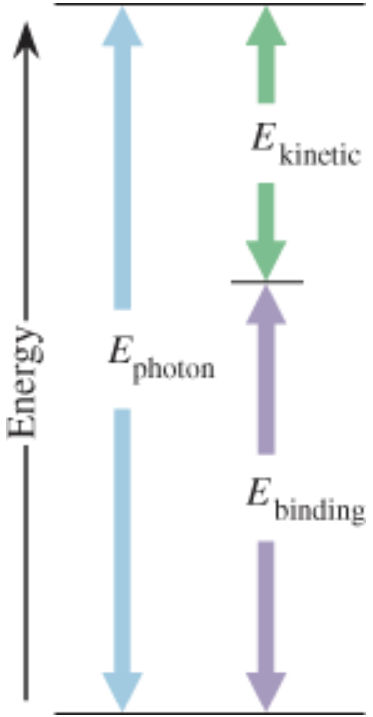
The Photoelectric Effect

$E_{h\nu}$



BE = binding energy

E_k= kinetic energy

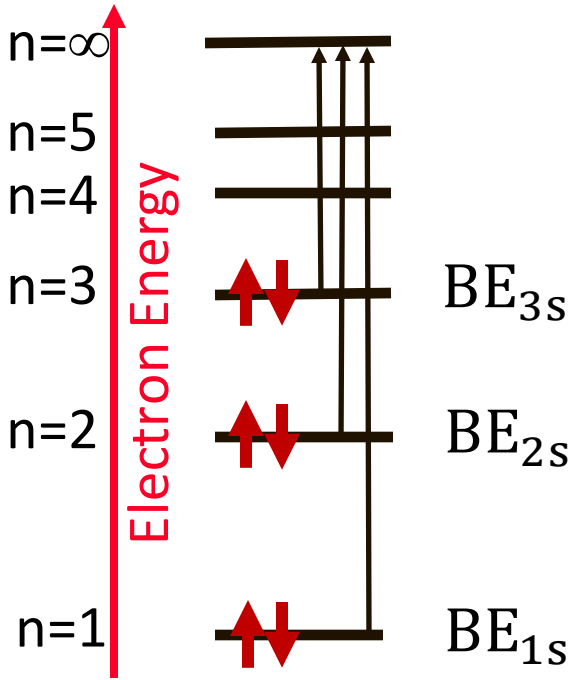


$$E_{in} = E_{out}$$

$$E_{h\nu} = BE + E_k$$

Work function vs. Binding energy

$$BE_{1s} > BE_{2s} > BE_{3s}$$



Φ = work function = minimum energy required to remove an electron from **metal (solid) surface**

Every electron has a binding energy whether it is a discrete atom, molecule, or material. The work function is the **smallest binding energy** for an atom, molecule, or material.

$$\text{Work function} = BE_{3s}$$

Calculating the wavelength of EMR

The work function of gallium metal is 417 kJ/mol.

What is the maximum wavelength of electromagnetic radiation that will cause electrons to be ejected from the surface of gallium metal?

Calculating the kinetic energy of ejected electrons

Calculate the kinetic energies of electrons ejected from metal B by photons with wavelength of 125 nm.

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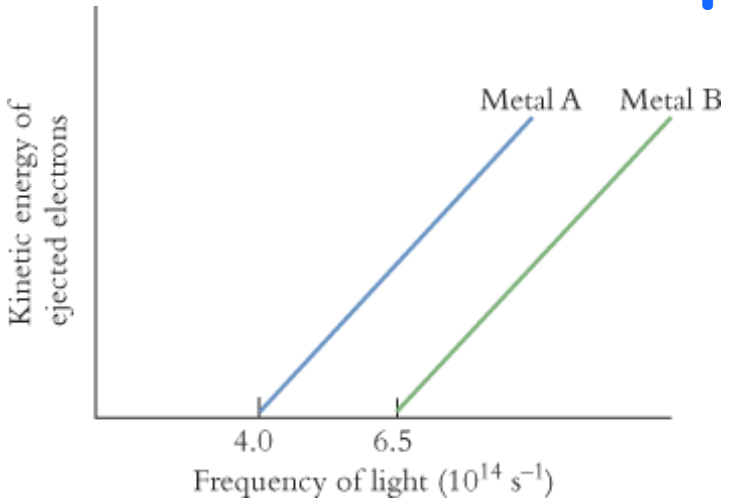


Which metal has the higher work function?

Challenge: Calculating the velocity of electrons

Bonus: How fast will the electrons be moving (assume they're in a vacuum and not interacting)? $m_e = 9.109 \times 10^{-31}$ kg

Application with gases: Reactions in the Ozone layer

- Ozone (O_3) layer has important consequences for life on earth.
- O_3 absorbs most UV-B light and UV-C light, which is harmful to living organisms
- Depletion of O_3 molecules prevents absorption of harmful radiation that can increase death rates for almost all living species

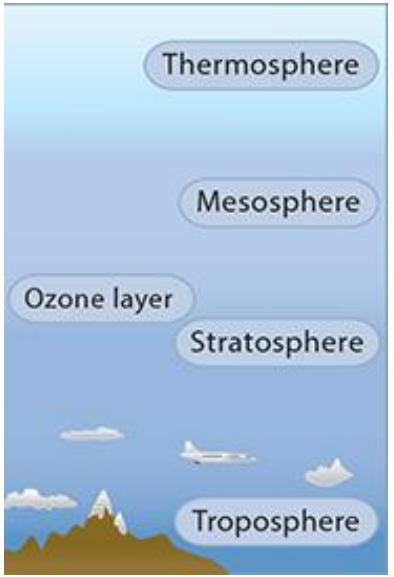
Ozone depletion involves how certain industrially produced chemicals containing bromine or chlorine are damaging the earth's protective stratospheric ozone layer.

$$O_3 \overset{h\nu}{\rightleftharpoons} O_2 + O \quad (1)$$

$$Cl + O_3 \longrightarrow ClO + O_2 \quad (2)$$

$$ClO + O \longrightarrow Cl + O_2 \quad (3)$$

$$2\,O_3 \longrightarrow 3\,O_2 \quad (4)$$



Calculating Ionization (minimum) Energy

Light of wavelength 340 nm or shorter is required to fragment ozone molecules. What is the minimum ionization energy in kJ/mol for this process?

$$E = \frac{h \cdot c}{\lambda}$$

Extra practice! Calculating Kinetic Energy

If an ozone molecule absorbs a 250 nm photon, how much excess kinetic energy will the fragments possess?

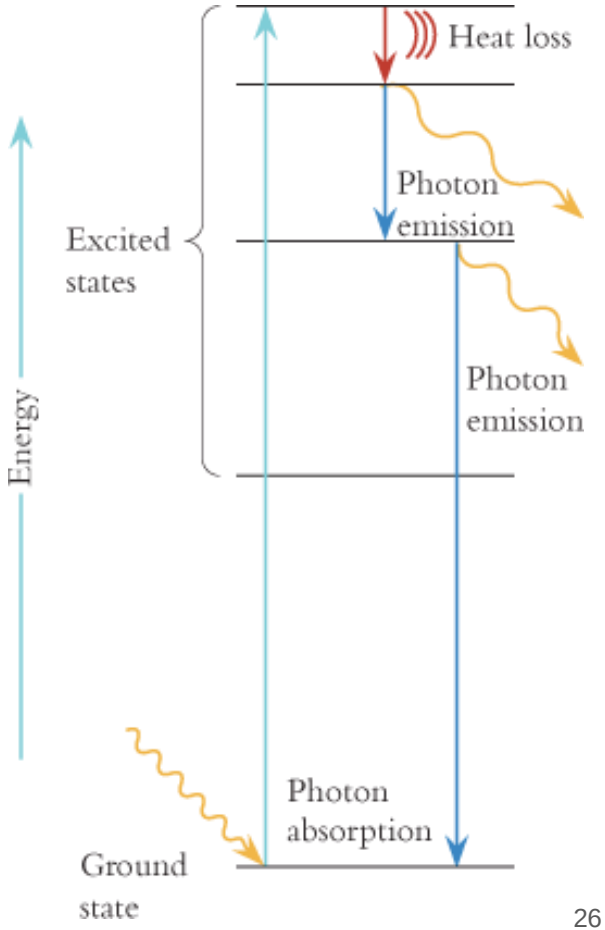
$$E = \frac{h \cdot c}{\lambda}$$

Studying the atom using EMR

Atoms can absorb and emit photons

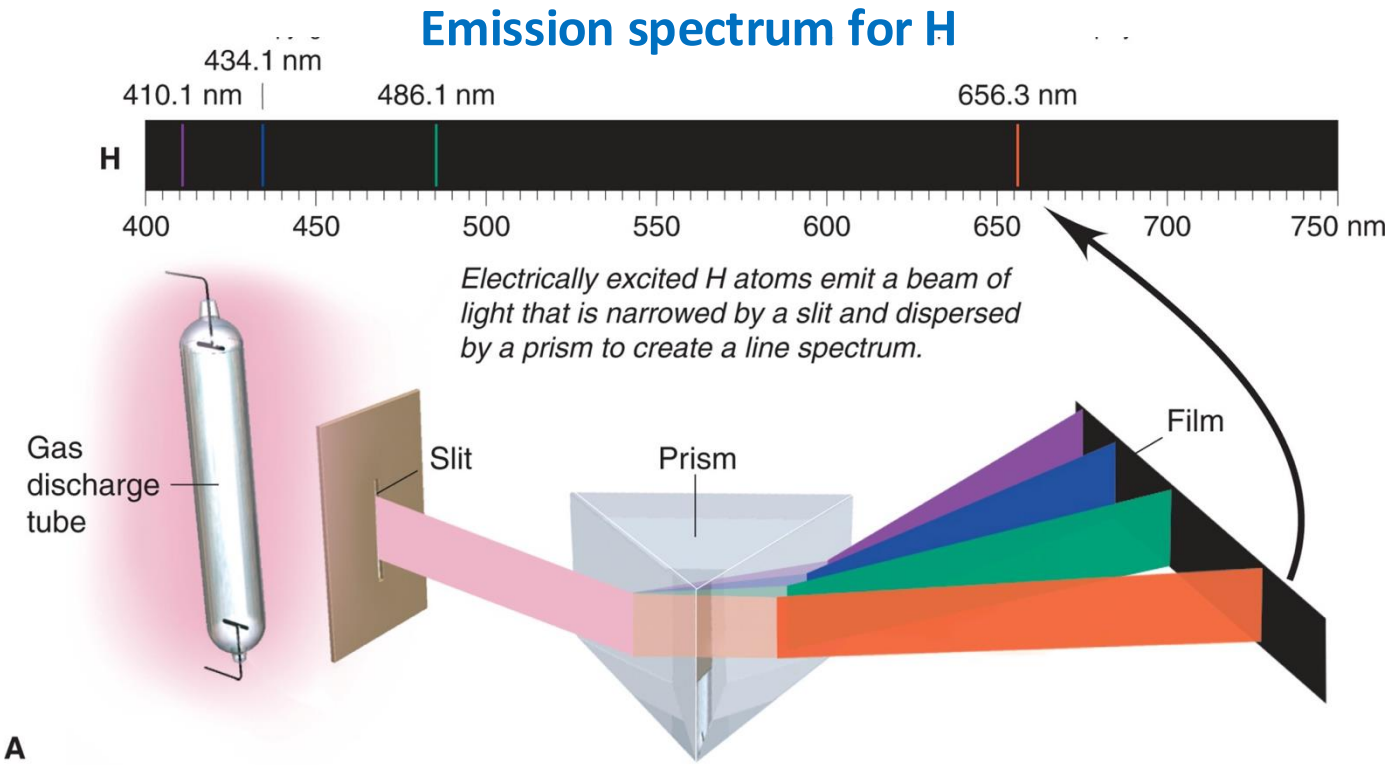
- Photon absorption by the atom increases the energy of the outmost election
  (absorbs energy to move to higher energy states)

- When this electron returns to its origin energy, it can release a photon
  (releases energy to fall to lower energy states)



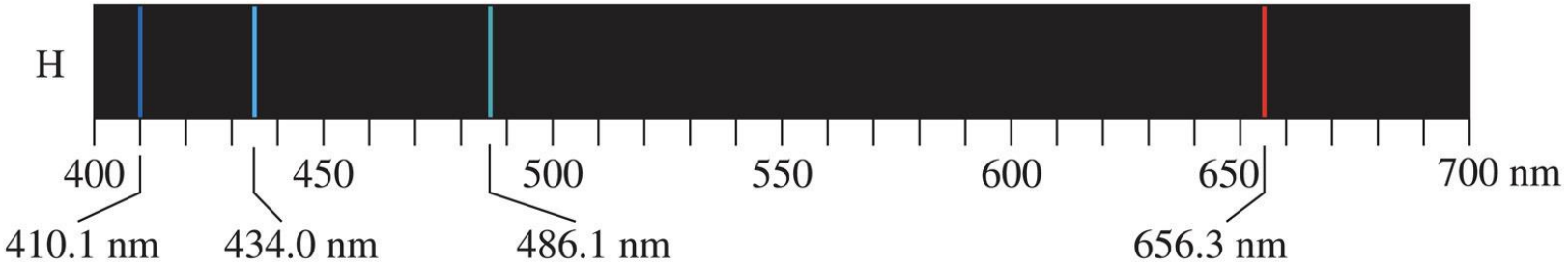
Each atom has its own unique EMISSION spectrum

When an electric discharge is passed through a glass tube containing a gaseous element it produces coloured light.

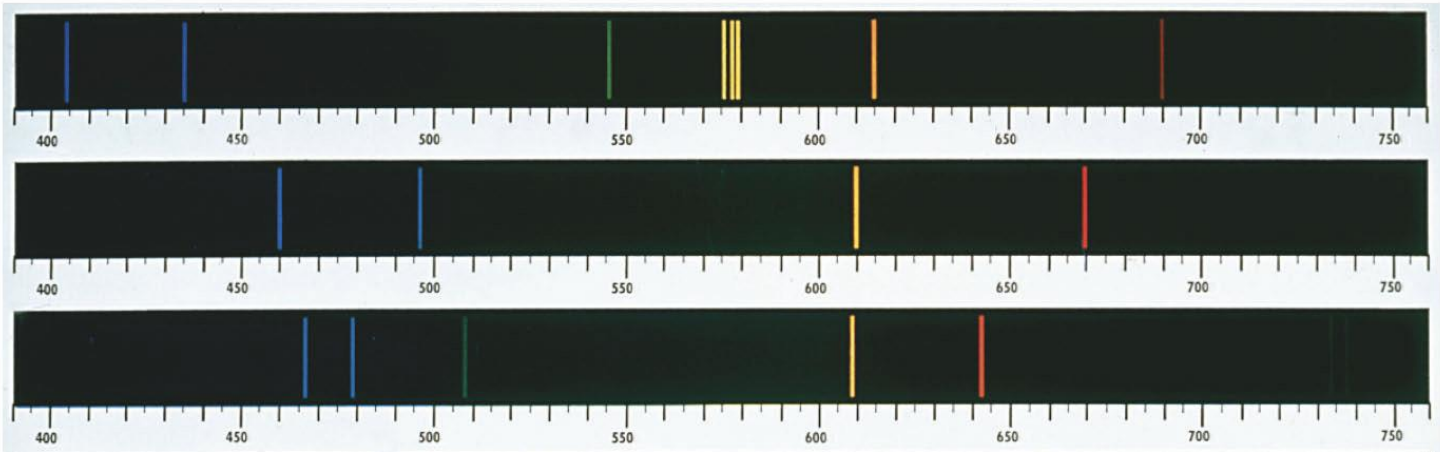


Each atom has its own unique EMISSION spectrum

Visible lines in H atom spectrum called the **BALMER** series.

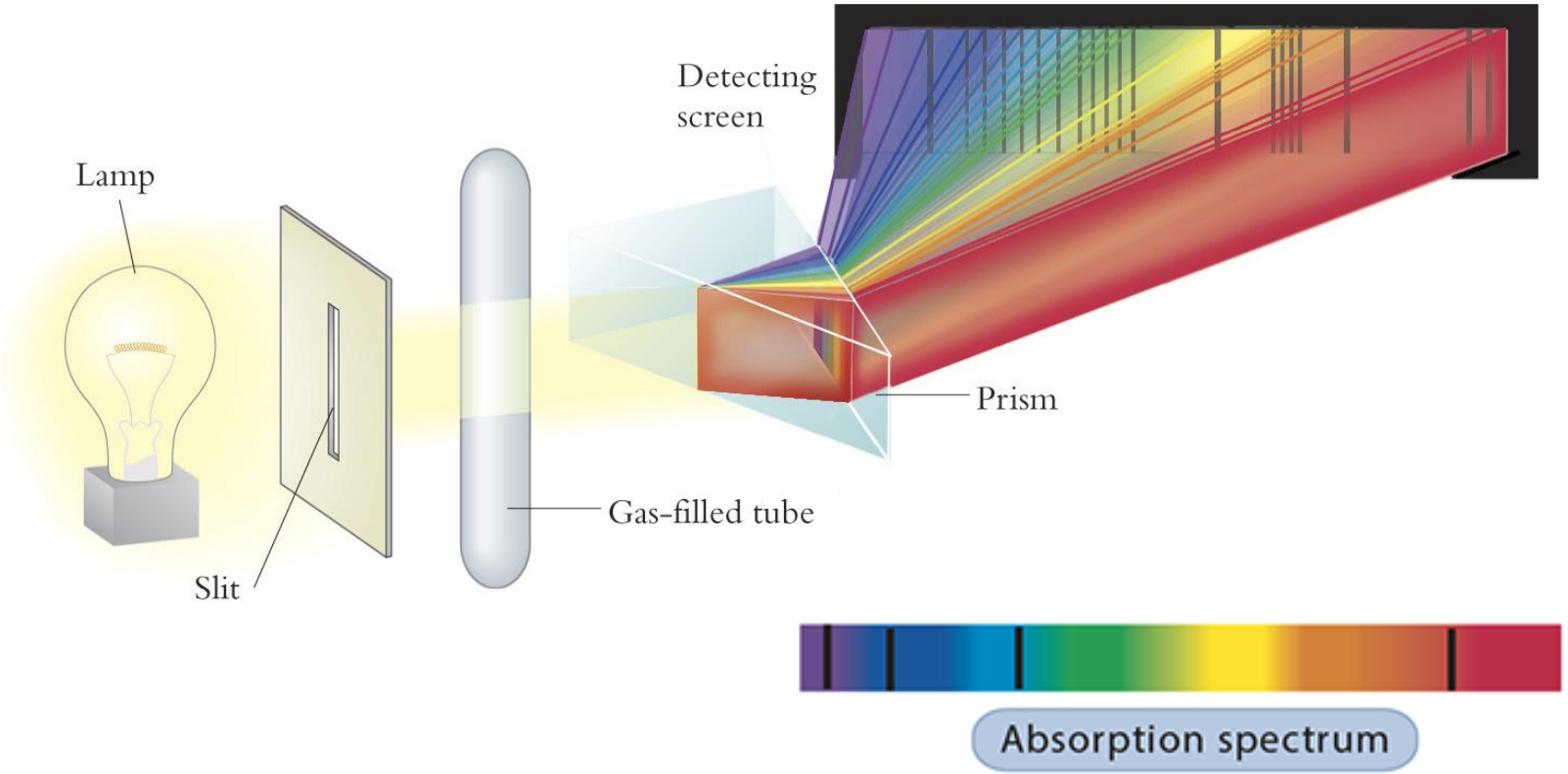


High E
Short λ
High υ



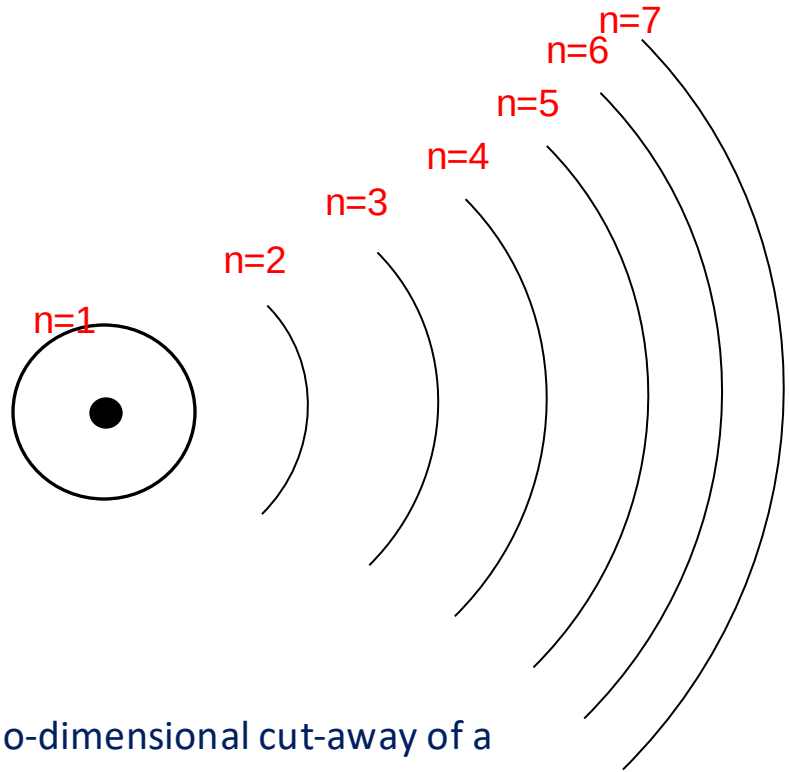
Low E
Long λ
Low υ

Each atom has its own unique ABSORPTION spectrum



Energies of electrons in atoms are quantized!

The Bohr Model of the Atom

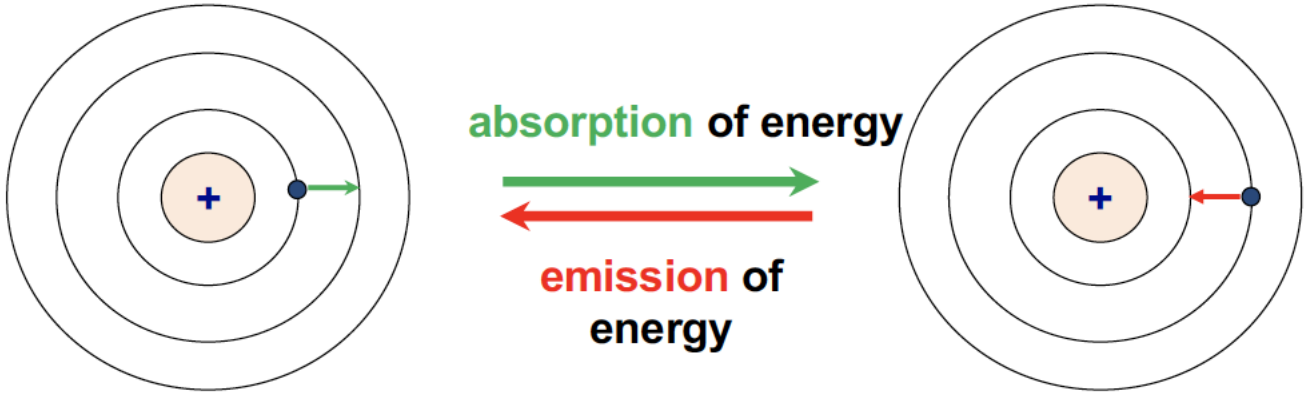


Two-dimensional cut-away of a three-dimensional picture.

- Bohr was the first to connect line spectra of atoms and the idea of quantized energy
- Proposed an orbit model for the atom, where electron orbits cannot just take any value; instead they are "**quantified**"; only certain orbits, defined by a whole number ***n*** are permitted
- While in an orbit, an electron neither absorbs nor emits radiation

Suppose we allow the atom to absorb energy… what happens?

Energy and the Bohr Model of the Atom



n = 1
Ground state

n = 2
Excited state

1) When an atom **absorbs** energy, an electron jumps from the ground state to an excited state
2) When the electron returns to the ground state, it **emits** the excess energy in the form of (kinetic energy) heat or (a new photon) scattered light

Energy of the 'Orbit': Rydberg Equation

- Each orbit is assigned a principal quantum number (*n*) which is a whole positive number (n = 1, 2, 3….)
- The potential energy associated with each orbit/ the energy gap between the energy levels can be calculated for the H atom: **Rydberg Equation**

$$E_{gap/photon} = R_H \left(1/n_i^2 - 1/n_f^2\right)$$

R_H : Rydberg constant
2.18×10^{-18} J

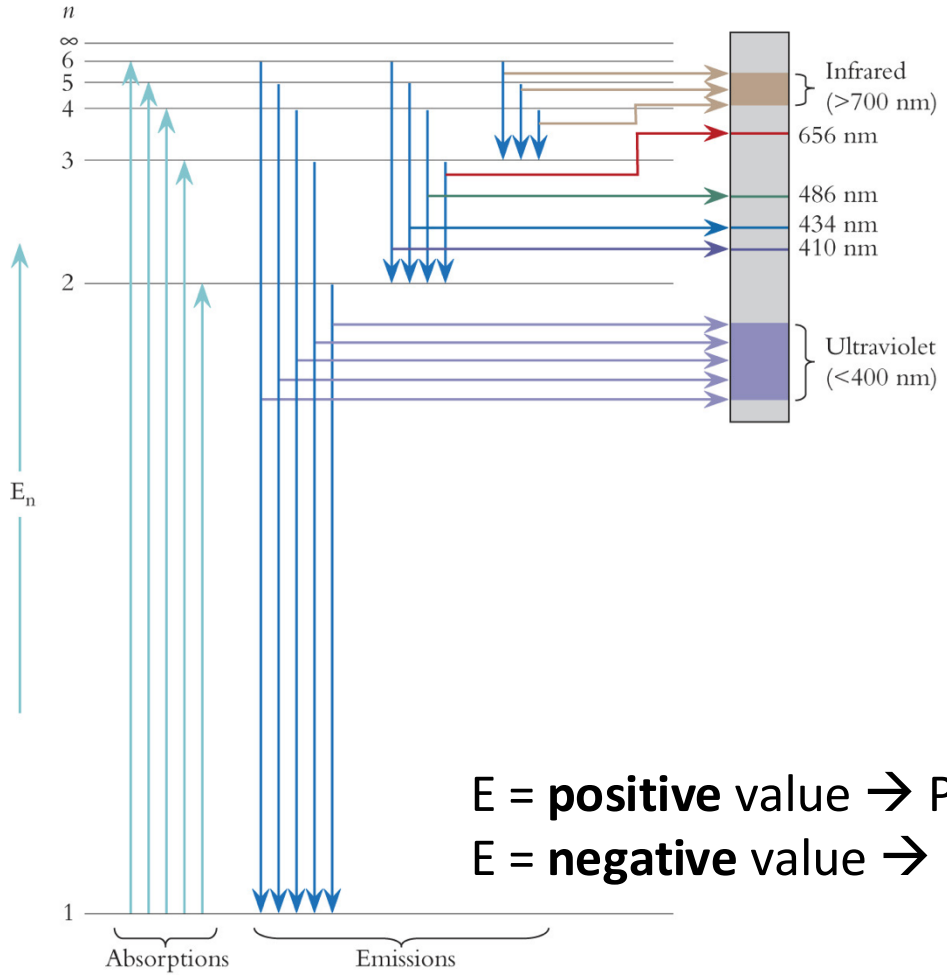
n_i: electron's initial level

n_f: electron's final level

$$E_{photon} = h\nu = \frac{h \cdot c}{\lambda}$$

The energy of the absorbed or emitted photon .

Line Spectrum of H Revealed



- Every time the atom absorbs or emits light, an electron moves from one orbital (n_i) to another (n_f)

E = **positive** value → Photon is **absorbed** by the atom

E = **negative** value → Photon is being **emitted** by the atom

Rydberg Equation: emission example

A hydrogen atom with its electron in the n = 6 energy level emits a photon of IR light. Calculate the change in energy of the atom and the wavelength of the emitted photon.

$$E = \frac{h \cdot c}{\lambda} \qquad E = R_H \left(1/n_i^2 - 1/n_f^2\right)$$

R_H : 2.18×10^{-18} J

What's my transition?

wooclap

What electronic transition would correspond to the emission of a photon with the shortest wavelength?

A) From n=1 to n=2
B) From n=4 to n=1
C) From n=2 to n=1
D) From n=1 to n=4

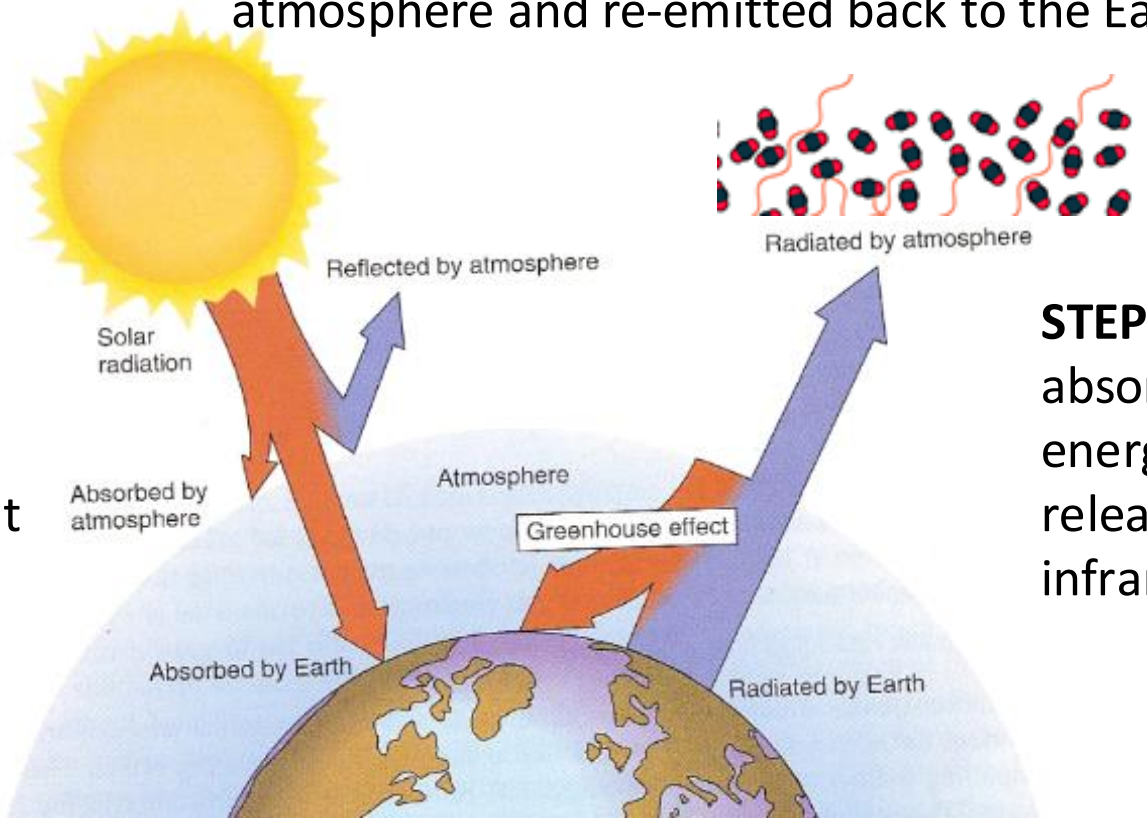
$$E = \frac{h \cdot c}{\lambda}$$

Hint: look at relationships in the equation

Connecting concepts to the Greenhouse Effect

STEP 3: Some energy is absorbed by gases in the atmosphere and re-emitted back to the Earth's surface.

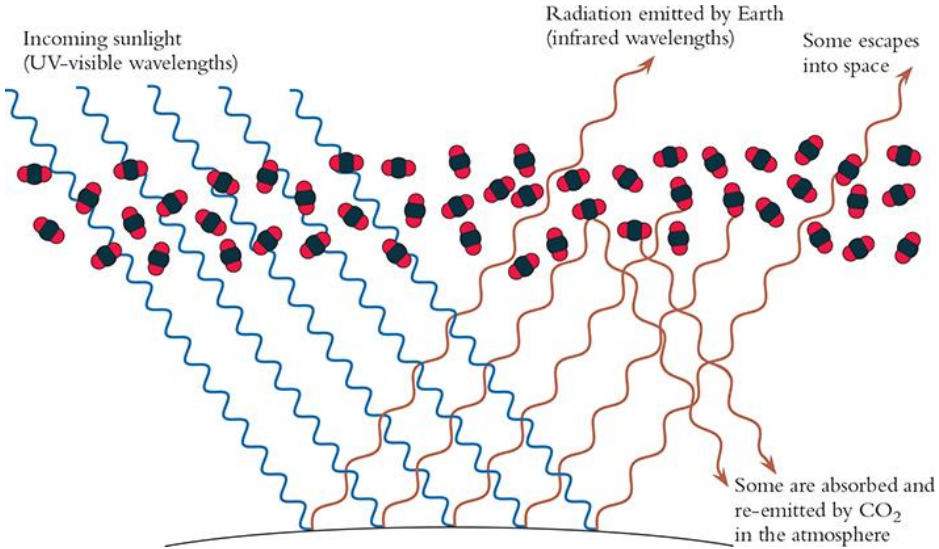
STEP 1: Earth receives energy from the sum (EMR), most of it in the form of visible light.



STEP 2: Earth absorbs the solar energy and releases it as infrared radiation.

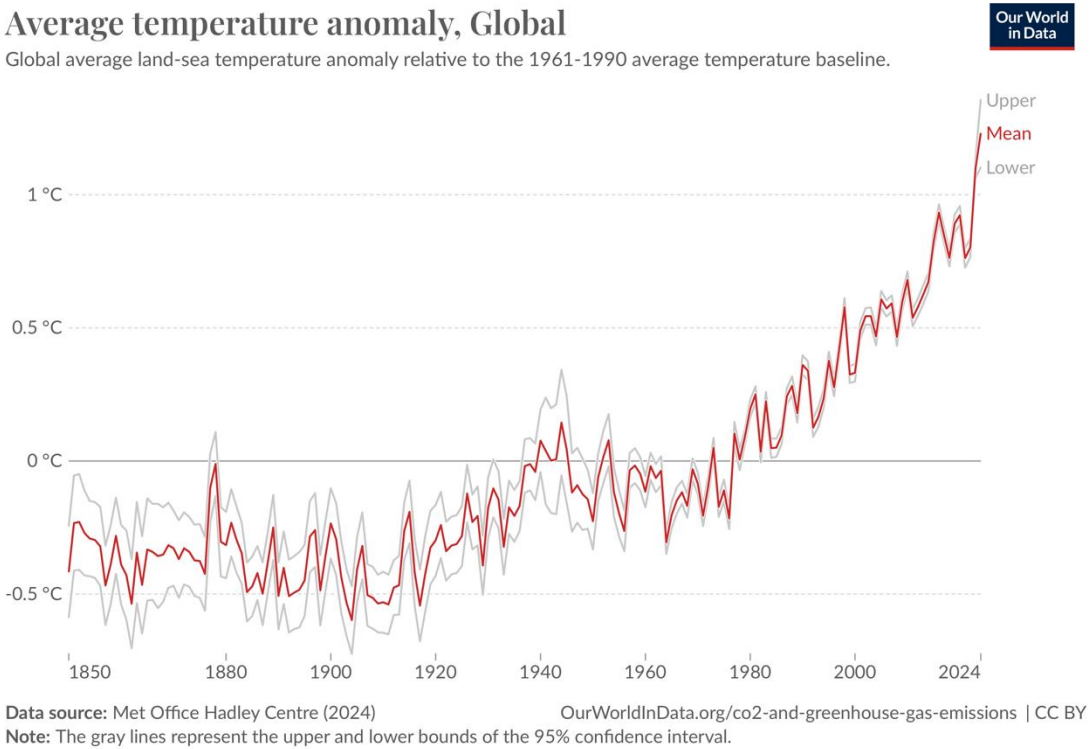
Role of atmospheric CO_2 in the Greenhouse Effect

- Carbon dioxide is transparent to the incoming sunlight, but it absorbs and re-emits a significant amount of the infrared radiation emitted by the earth
- This alters Earth's energy balance, raising its average temperature
- Excess emissions of CO_2 and other greenhouse gases from human activities are warming Earth's climate at a problematic rate



Role of atmospheric CO_2 in the Greenhouse Effect

Excess emissions of CO_2 and other greenhouse gases from human activities are warming Earth's climate at a problematic rate.



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What is your role in helping to reduce greenhouse gas/carbon dioxide emissions?

1. **PHASE OUT** coal plants
2. **INVEST** in clean energy & efficiency
3. **RETROFIT** buildings
4. **DECARBONIZE** cement, steel & plastics
5. **SHIFT** to electric vehicles
6. **INCREASE** public transport
7. **DECARBONIZE** aviation and shipping
8. **HALT** deforestation & **RESTORE** degraded lands
9. **REDUCE** food loss and waste
10. **EAT** more plants & less meat

World Resources Institute (Source: IPCC AR6)