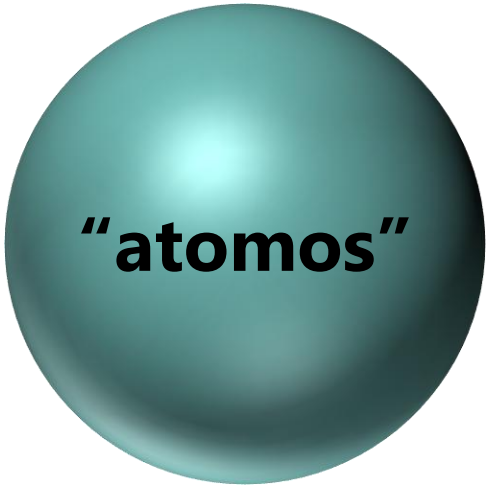
E.1

Structure of the Atom

IB PHYSICS | ATOMIC PHYSICS

The Atom

The Greek philosopher Democritus is credited for theorizing that matter divisibility can come to an end



Uncuttable

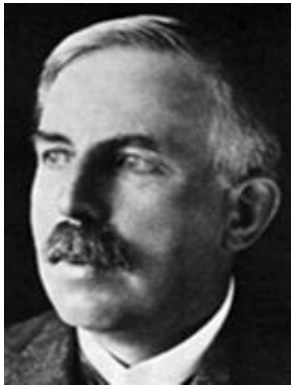
E.1

History of the Atom

Our understanding of the atom has **evolved**

Dalton

Thompson

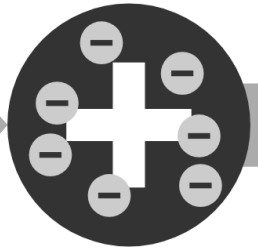


Rutherford

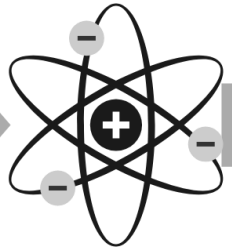
Bohr

Heisenberg

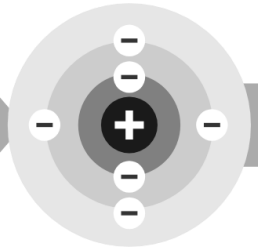
Ratios



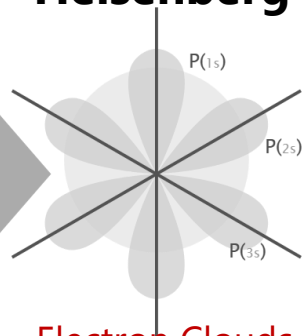
"Plum-Pudding"



Nucleus

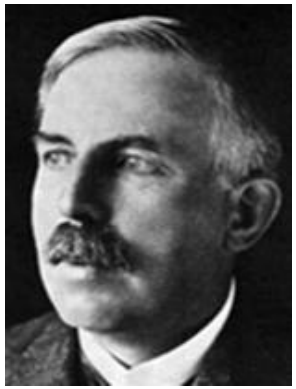


Energy Levels



Electron Clouds

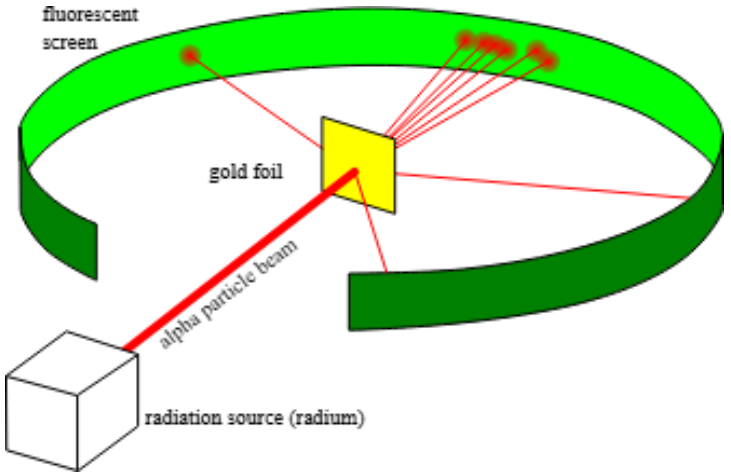
Discovering the Nucleus



Rutherford

Geiger

Marsden



The alpha particles that were deflected backwards are evidence of a tiny and dense nucleus in the center of the atom

Scale of the Atom

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Atoms are mostly empty space

If an atom was enlarged to the size of a football stadium, the nucleus would be the size of a

A blueberry/marble

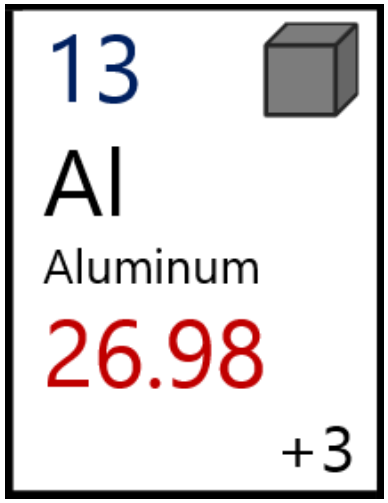
Standard Notation

What do you notice about the notation written below?
Can you determine what each color represents?

Mass Number

$^{27}_{13}Al$

Atomic Number



$^{A}_{Z}X$

Try This

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$^{23}_{11}Na$

Mass Number	23
Atomic Number	11
# of Protons	11
# of Neutrons	12

$^{25}_{12}Mg$

Mass Number	25
Atomic Number	12
# of Protons	12
# of Neutrons	13

E.1

Sample IB Question

A nucleus of Californium (Cf) contains 98 protons and 154 neutrons. Which of the following correctly identifies this nucleus of Californium?

$^{98}_{254}\mathrm{Cf}$

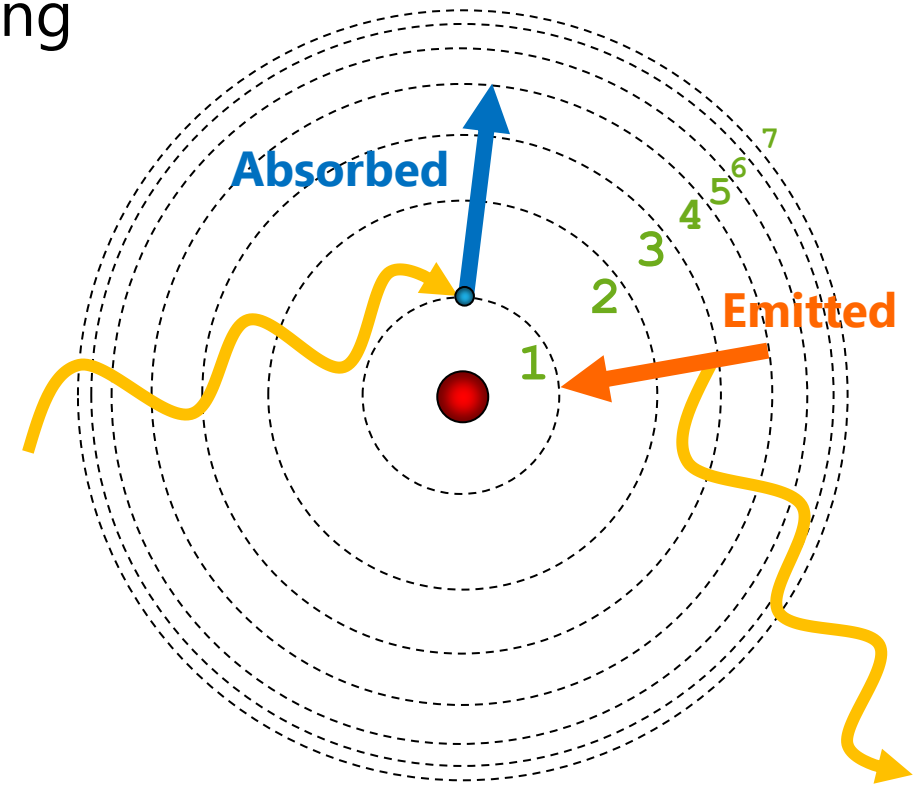
$^{252}_{98}\mathrm{Cf}$

$^{154}_{98}\mathrm{Cf}$

$^{350}_{154}\mathrm{Cf}$

Energy Levels

Electrons in an atom exist at specific energy levels and can move up and down by absorbing and emitting energy



Light is Quantized

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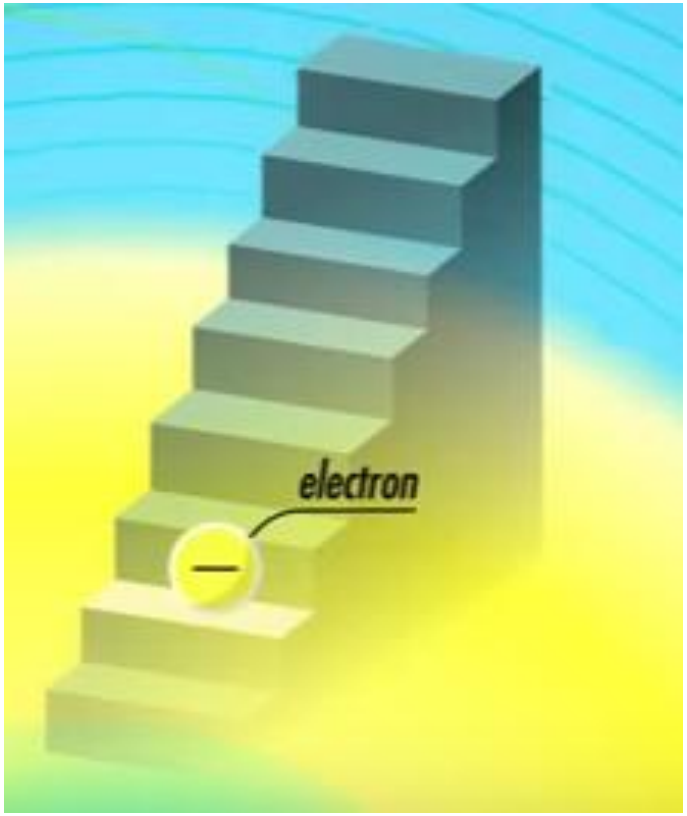
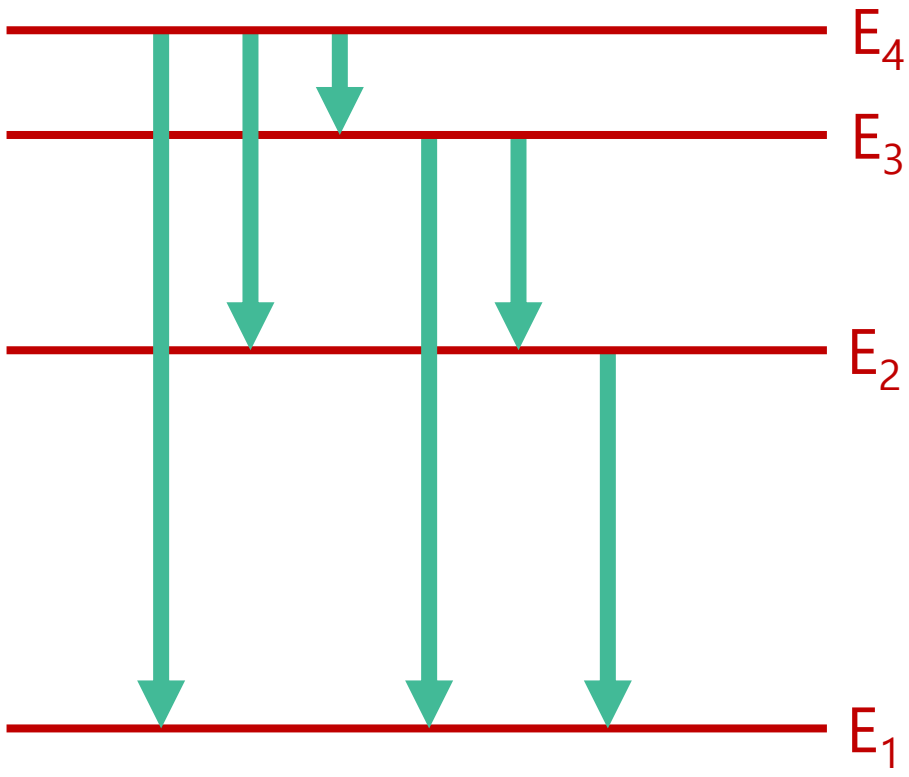
Photons of light can only have certain discrete values of energy



Energy Levels

A photon is emitted whenever an electron transitions from one energy level down to a lower energy level

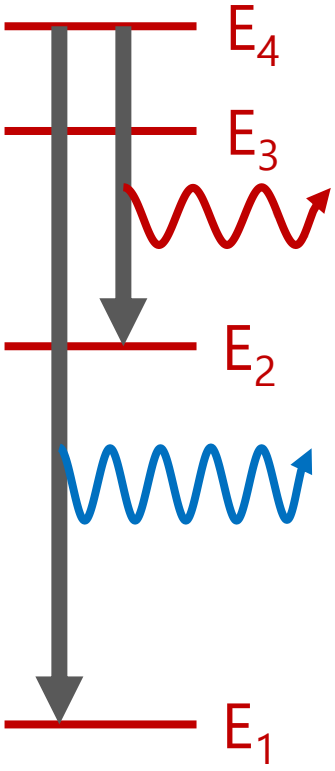


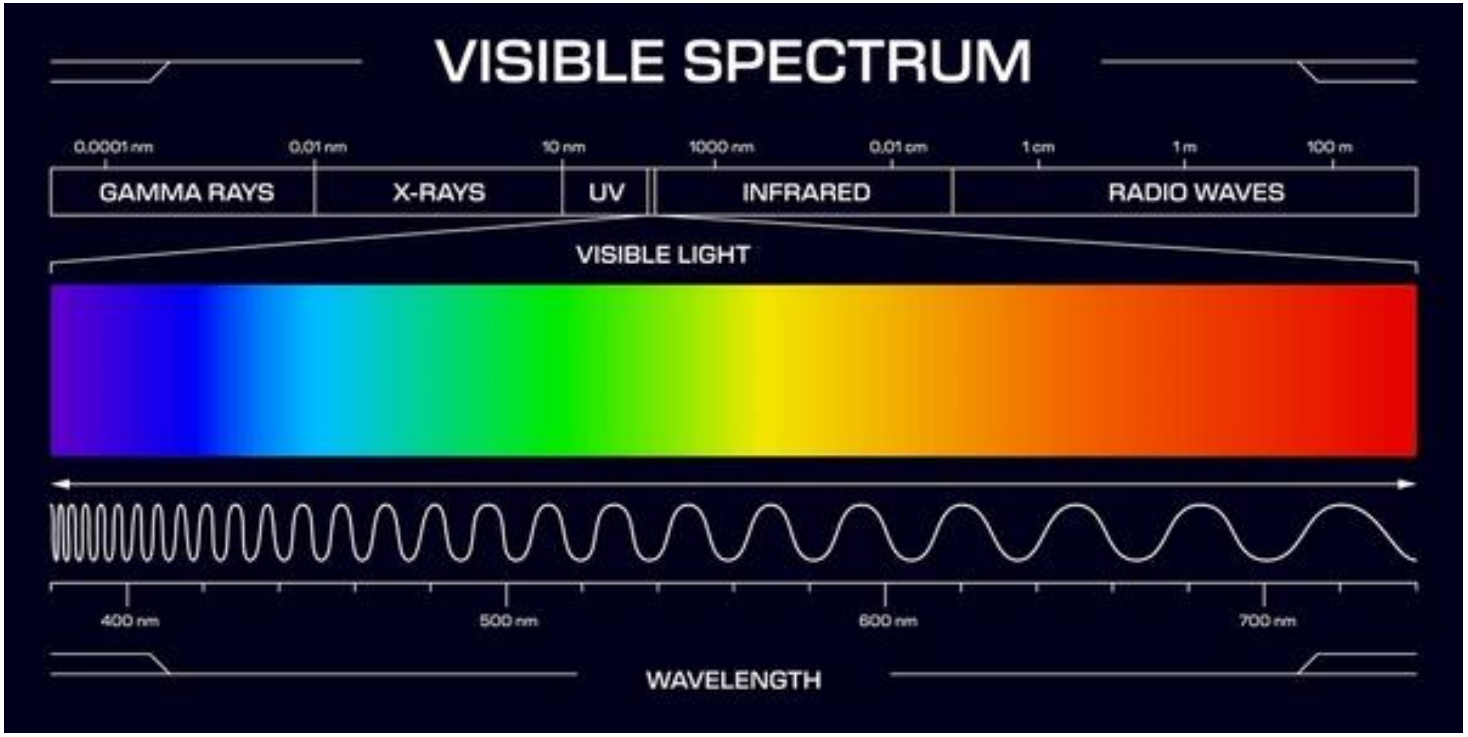
How many different transitions are possible between these four energy levels?

6

Energy Levels

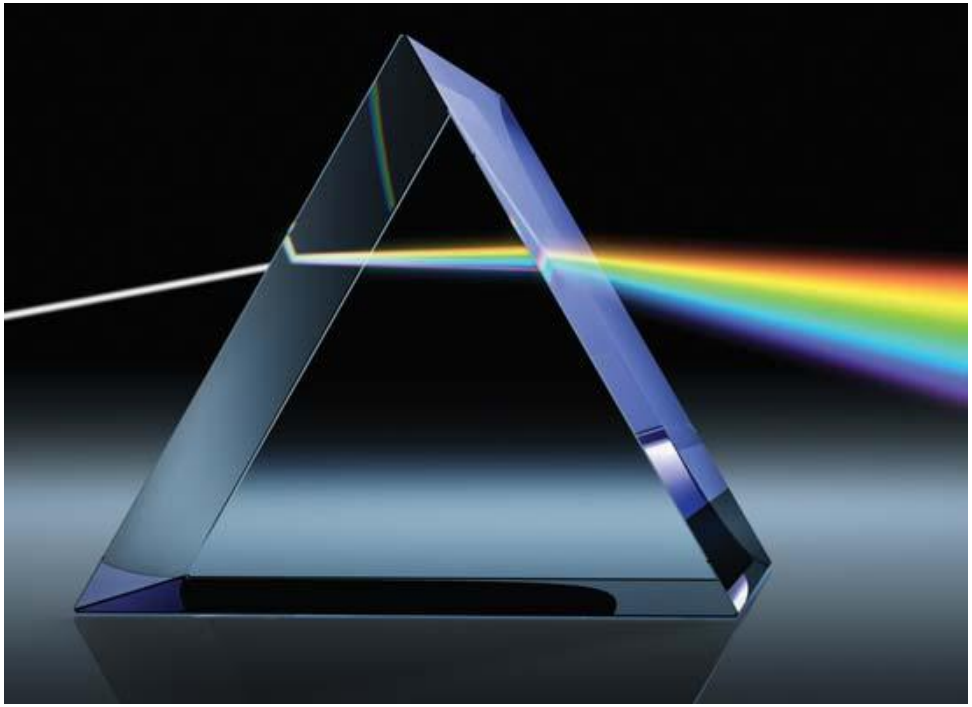
The amount of energy in the electron jump determines the color (or type) of light emitted





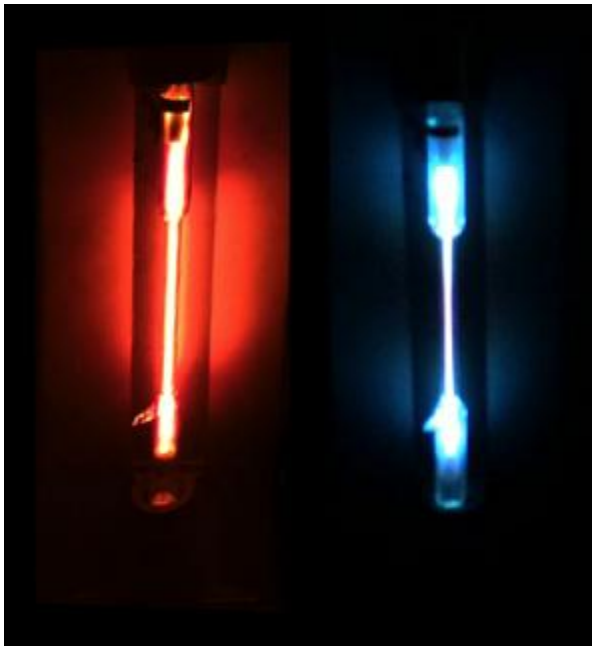
Continuous Spectrum

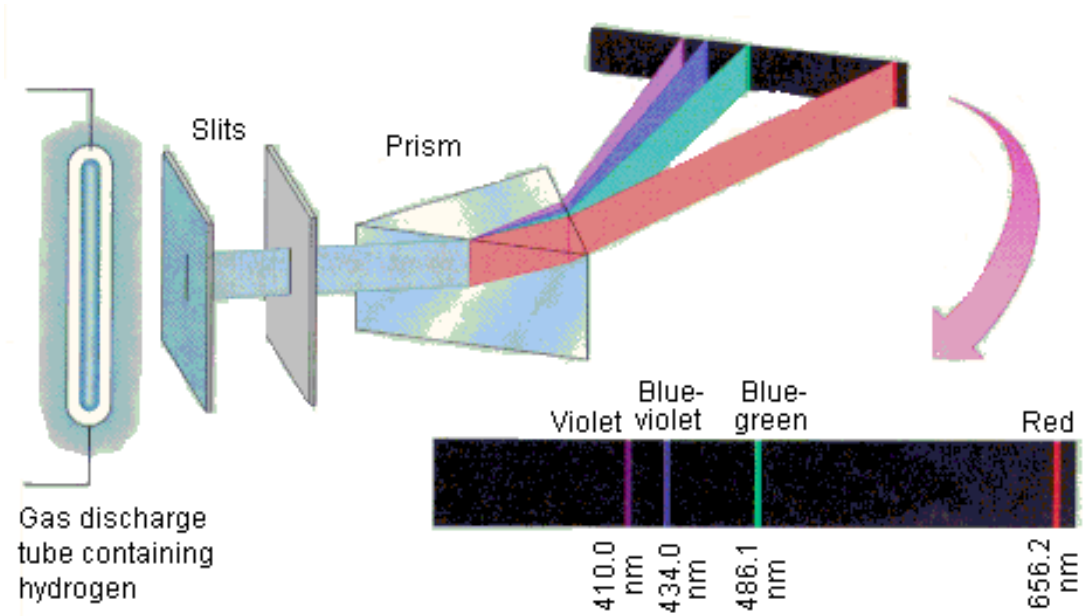
When white light from the sun passes through a prism, the light is dispersed into its component colors in a continuous spectrum



Emission Spectrum

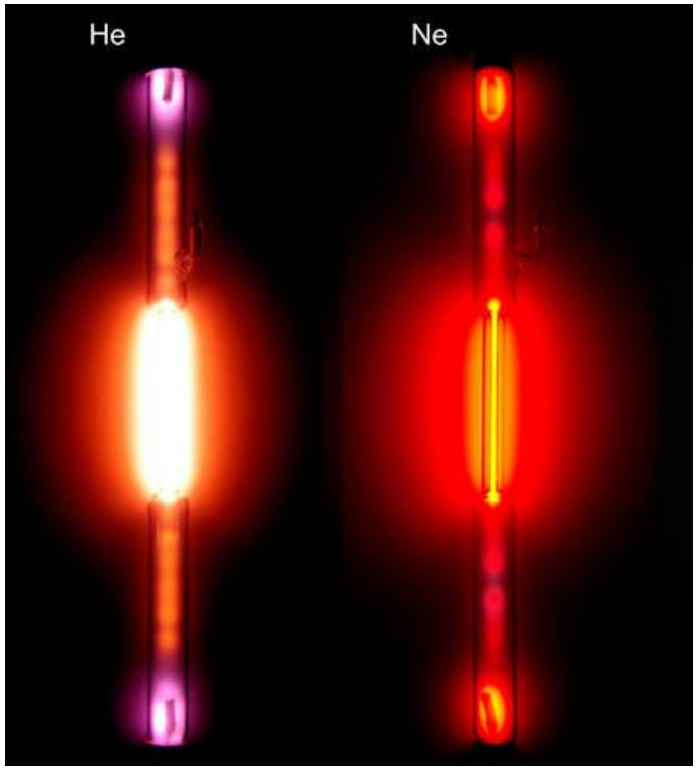
If an electric current is passed through an element in the form of a low-pressure gas, it will produce its own unique emission spectrum



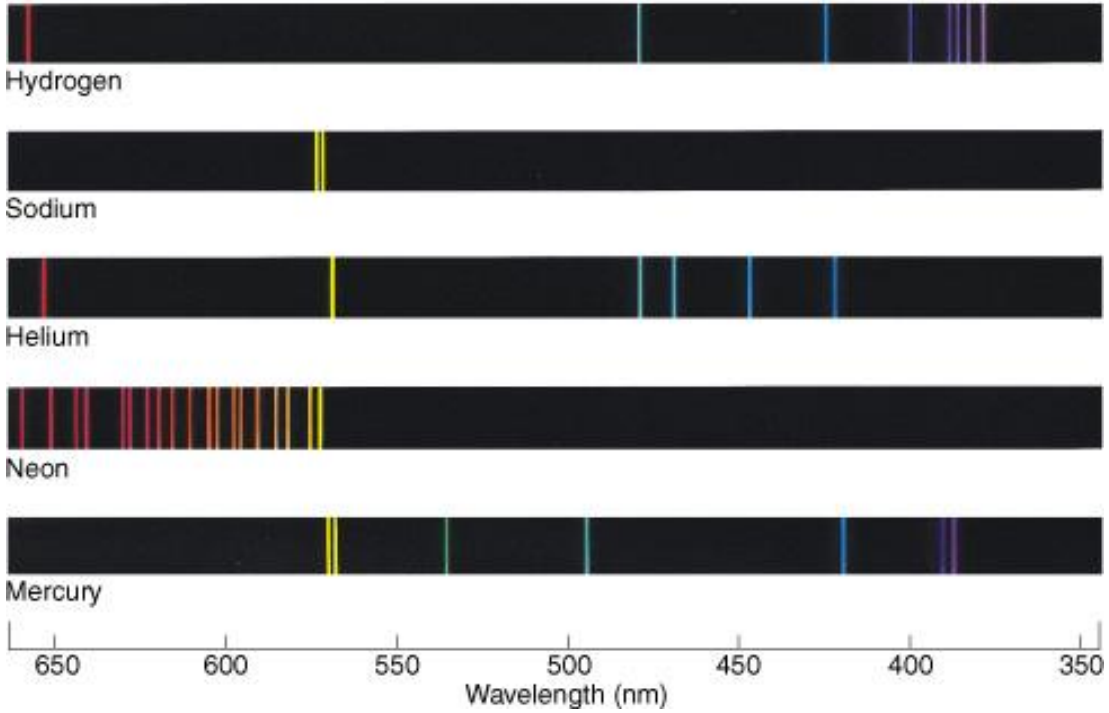


Emission Spectrum

These spectra can be used to identify elements like a fingerprint



These are known as Line Spectra



Energy of a Photon

$$E = hf$$

Energy
[J]

Frequency
[Hz]

Planck's Constant	h	6.63×10^{-34} J s

E.1

IB Physics Data Booklet

E. Nuclear and quantum physics

Standard level and higher level	
E.1 Structure of the atom	$E = hf$
E.3 Radioactive decay	$E = mc^2$
E.5 Fusion and stars	$\text{d(parsec)} = \frac{1}{\text{p(arc-second)}}$

C.2 Wave model	$v = f\lambda = \frac{\lambda}{T}$

Fundamental constants

Quantity	Symbol	Approximate value
Speed of light in vacuum	c	$3.00 \times 10^{8}\ \text{m s}^{-1}$
Planck constant	h	$6.63 \times 10^{-34}\ \text{J s}$
Elementary charge	e	$1.60 \times 10^{-19}\ \text{C}$

$$c = f\lambda \qquad f = \frac{c}{\lambda}$$

$$E = h\left(\frac{c}{\lambda}\right)$$

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

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

What's an eV??

$$eV \rightarrow electron - volts$$

Unit of Energy (required to move one electron across 1 V)

$$\{Energy\ in\ eV\} = \frac{\{Energy\ in\ J\}}{1.60 \times 10^{-19}}$$

Try This…

E.1

Calculate the energy carried by one photon of microwaves of wavelength 9 cm (as might be used in wifi signals) in J and eV

0.09 m

$$E = \frac{hc}{\lambda} = \frac{(6.63 \times 10^{-34})(3 \times 10^{8})}{(0.09)} = \boxed{2.21 \times 10^{-24}\ \text{J}}$$

$$\frac{2.21 \times 10^{-24}}{1.60 \times 10^{-19}} = \boxed{1.38 \times 10^{-5}\ \text{eV}}$$

Shortcut time ☺

Unit conversions

$$1\ \text{radian (rad)} \equiv \frac{180^\circ}{\pi}$$

$$\text{Temperature (K)} = \text{temperature (°C)} + 273$$

$$1\ \text{light year (ly)} = 9.46 \times 10^{15}\ \text{m}$$

$$1\ \text{parsec (pc)} = 3.26\ \text{ly}$$

$$1\ \text{astronomical unit (AU)} = 1.50 \times 10^{11}\ \text{m}$$

$$1\ \text{kilowatt-hour (kWh)} = 3.60 \times 10^{6}\ \text{J}$$

$$hc = 1.99 \times 10^{-25}\ \text{Jm} = 1.24 \times 10^{-6}\ \text{eV m}$$

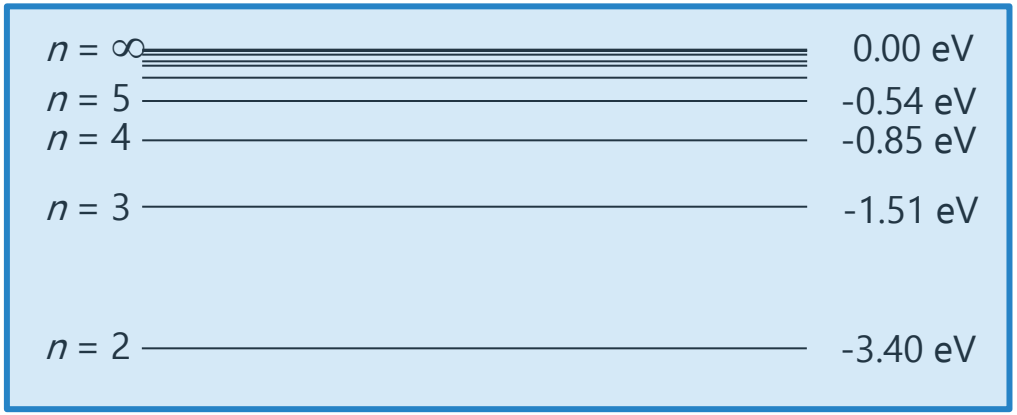
Since h and c are both constants, hc acts as a constant as well

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

$$\frac{1.99 \times 10^{-25}\ \text{J}\cancel{\text{m}}}{0.09\ \cancel{\text{m}}} = 2.21 \times 10^{-24}\ \text{J}$$

$$\frac{1.24 \times 10^{-6}\ \text{eV}\cancel{\text{m}}}{0.09\ \cancel{\text{m}}} = 1.38 \times 10^{-5}\ \text{eV}$$

Energy Levels

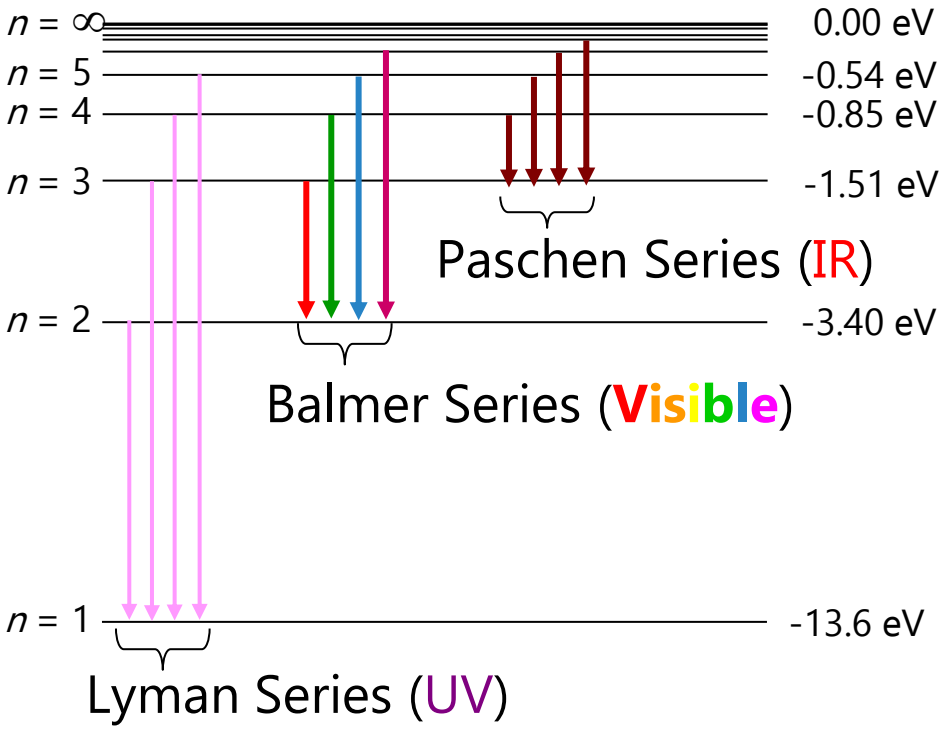


Excited States

Ground State

Energy Transitions

Different Energy transitions result in different energies (wavelengths) of light that are absorbed or emitted



Calculating Wavelength Emitted

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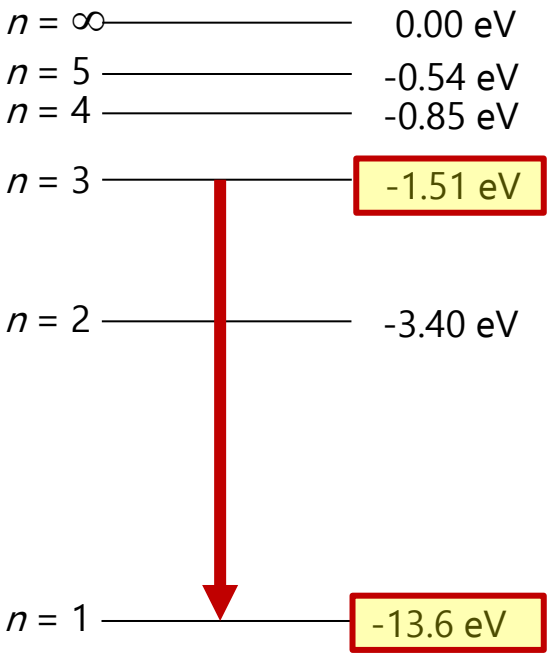


What is the wavelength emitted?

$$E = 13.6 - 1.51 = 12.09 \text{ eV}$$

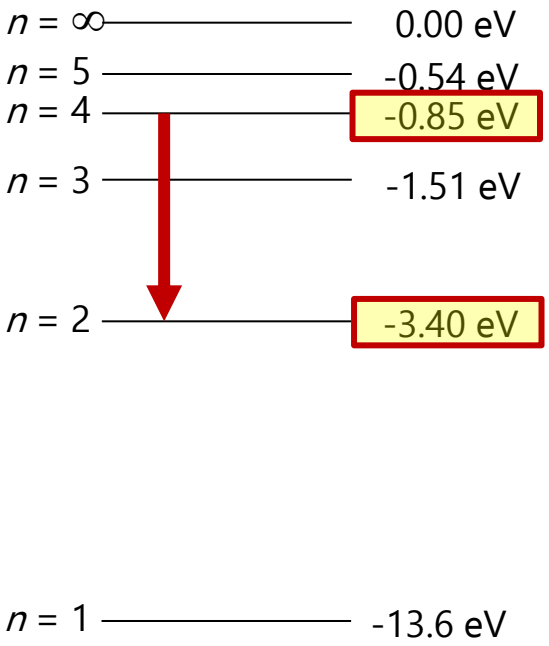
$$E = \frac{hc}{\lambda} \longrightarrow \lambda = \frac{hc}{E}$$

$$\lambda = \frac{1.24 \times 10^{-6} \text{ eV m}}{12.09 \text{ eV}} = 1.03 \times 10^{-7} \text{ m}$$

$$1.03 \times 10^{-7} \text{ m} \rightarrow 103 \text{ nm}$$

hc	1.99×10^{-25} J m	1.24×10^{-6} eV m

Try This…



What is the wavelength emitted?

$$E = 3.40 - 0.85 = 2.55 \text{ eV}$$

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

$$\lambda = \frac{1.24 \times 10^{-6} \text{ eV m}}{2.55 \text{ eV}} = 4.86 \times 10^{-7} \text{ m}$$

$$4.86 \times 10^{-7} \text{ m} \rightarrow 486 \text{ nm}$$

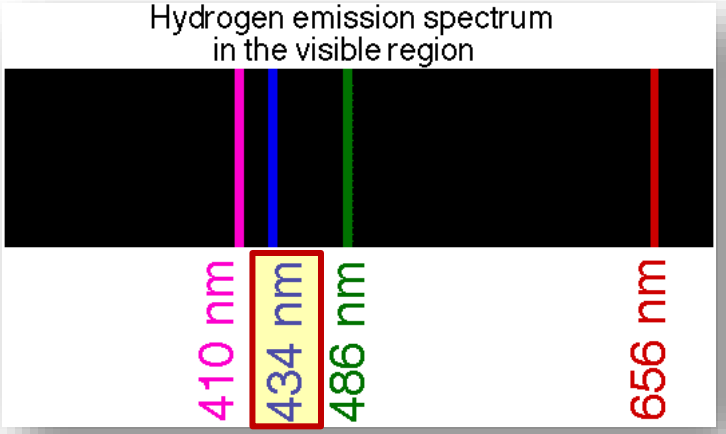
hc	1.99×10^{-25} J m	1.24×10^{-6} eV m

Working Backwards…

What is the energy in eV for a 434 nm blue emission line?

↓

434×10^{-9} m

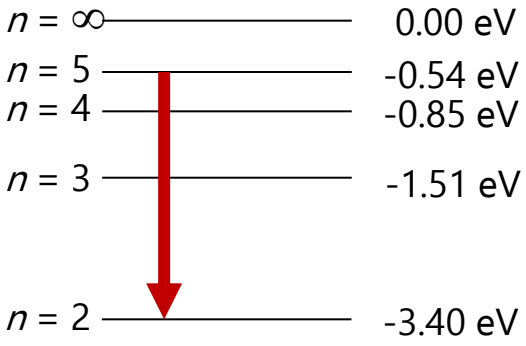


$$E = \frac{hc}{\lambda} = \frac{1.24 \times 10^{-6}\ \text{eV}\ \cancel{\text{m}}}{434 \times 10^{-9}\ \cancel{\text{m}}} = \boxed{2.86\ \text{eV}}$$

hc	1.99×10^{-25} J m	1.24×10^{-6} eV m

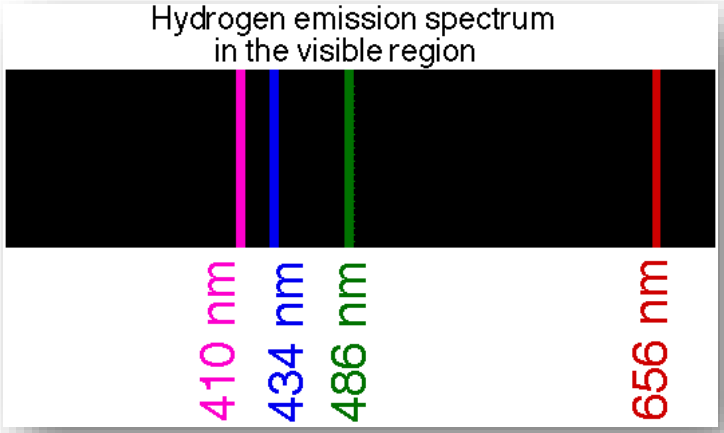
Working Backwards…

E.1



Draw in the Energy Transition for a 434 nm blue emission line?

What transition has an energy difference of 2.86 eV?



$$E = 3.40 - 0.54 = 2.86 \text{ eV}$$

E.1

Lesson Takeaways

- ❑ I can describe how the historical understanding of the atom has changed over time
- ❑ I can conceptually describe the Rutherford-Geiger-Marsden experiment and how it led to the discovery of the nucleus
- ❑ I can describe discrete electron energy levels and how transitions between these absorb and emit energy
- ❑ I can calculate the energy, frequency, and wavelength of light emitted by transitioning electrons
- ❑ I can identify and calculate the emission wavelengths for different elements