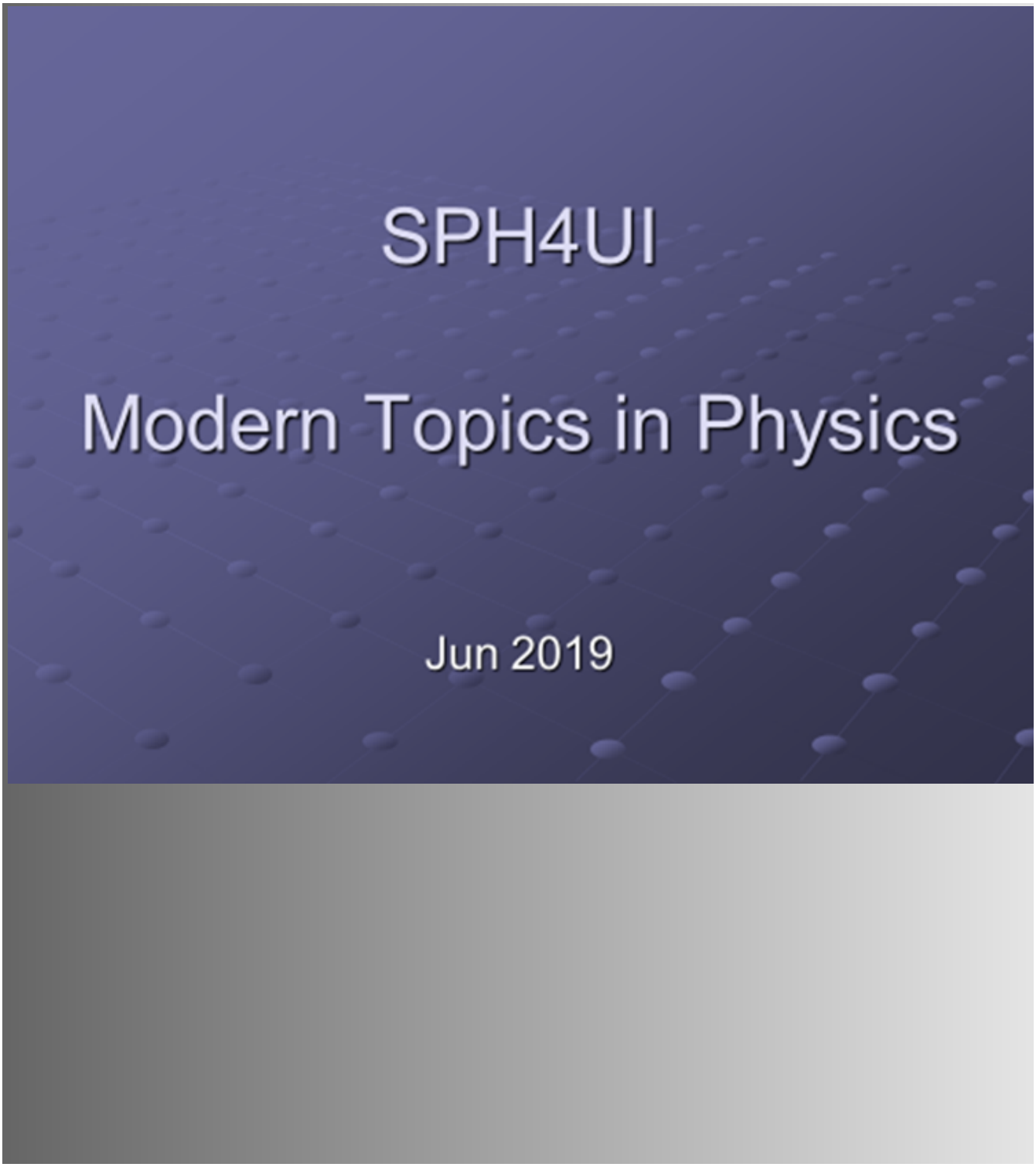

SPH4UI
Modern Topics in Physics
Jun 2019

Topics in Modern Physics

Relativity Quantum Mechanics

2 basic postulates:

- laws of physics are the same in all inertial frames of reference
- cosmic speed limit = c

1 basic postulate:

- light must carry energy in discrete quantities (E=hf)

h=6.626x10^{-34} m^{2}kg/s
- Called Planck's constant

From these two theories a whole new set of branches of physics was born

- Particle Physics
- Special and General Relativity
- Quantum Mechanics
- Cosmology
- Gravitation
- Quantum Information
- Quantum Fields and Strings
- Superconductivity
- Nuclear Physics
- Solid State Physics
- and more .....

Introduction to Modern Physics

Jun 2019

Quantum Mechanics
- Wave / Particle Duality
- The Standard Model of Particle Physics

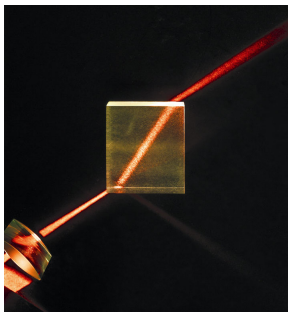
Relativity - Special and General

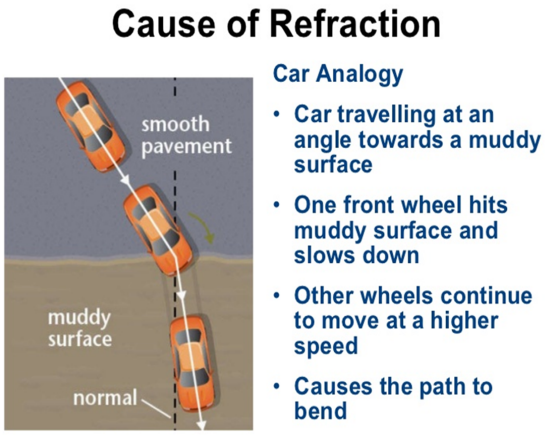
Jan 2019

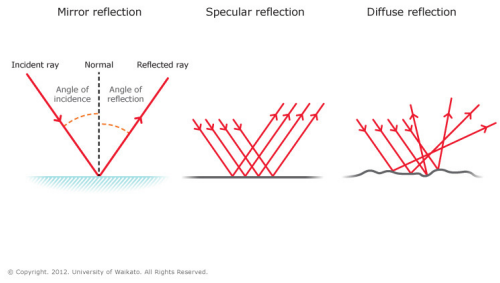
Wave Particle Duality

Wave / Particle Duality of Light

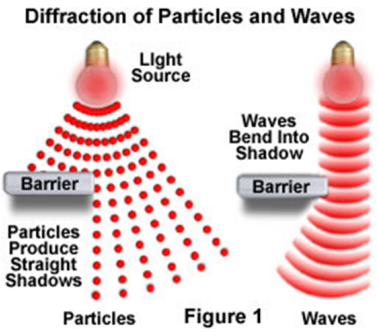
reflection and refraction can be explained by wave model or a particle model of light

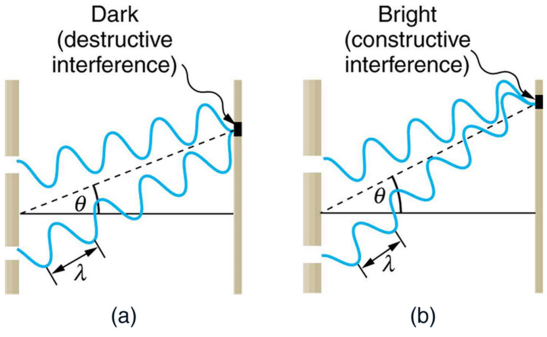


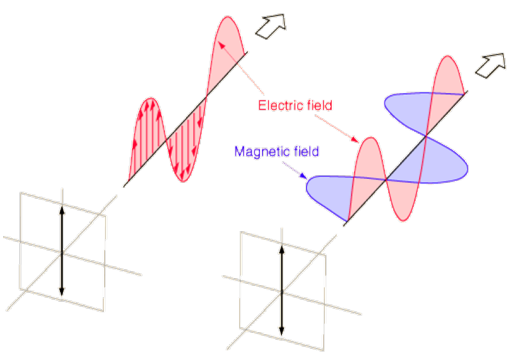




Diffraction, Interference and Polarization can only be explained by wave model







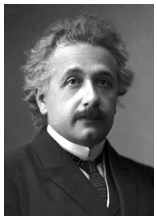
Quantum Mechanics

Wave vs Particle Nature of the World

Wave Particle Duality - is light a wave or a particle?

Wave / Particle Duality of Light:

Einstein *"It seems as though we must use sometimes the one theory and sometimes the other, while at times we may use either. We are faced with a new kind of difficulty. We have two contradictory pictures of reality; separately neither of them fully explains the phenomena of light, but together they do."*



Property	Wave Theory	Particle Theory
Reflection (bouncing)	✓	✓
Diffraction (spreading out)	✓	x
Refraction (bending)	✓	✓
Interference (adding or subtracting)	✓	x
Polarization (orientation)	✓	x

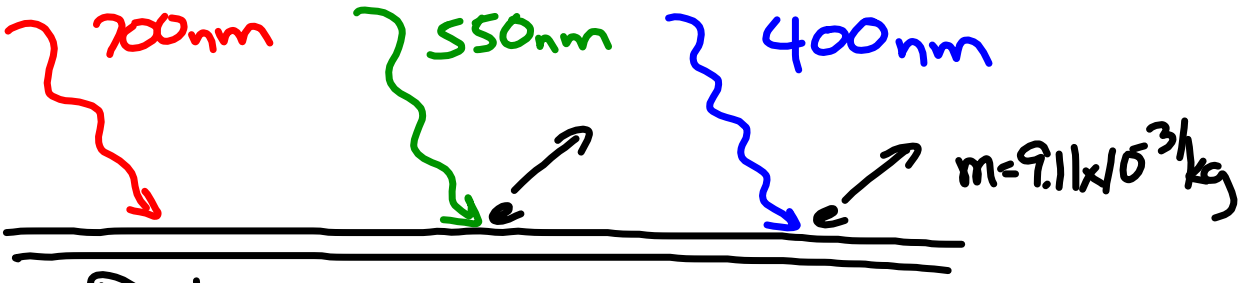
Key Discoveries Leading to Modern Quantum Theory

1887 – Heinrich Hertz discovers the Photoelectric Effect.

1900 – Max Planck suggests that Electro-Magnetic Energy can only be emitted in quantized form

1905 – Einstein uses Max Planck's quantization of light theory to explain the Photo-Electric Effect

The Photoelectric Effect



Potassium → work function 2.0eV
(energy required to remove an electron)

$E = hf$

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

$= 2.84 \times 10^{-19}\ J$

$= 1.8\ eV$

will not escape

$E < 2.0$

$1eV = 1.602 \times 10^{-19}\ J$

$3.61 \times 10^{-19}\ J$

$2.3eV$

$2.0eV$ to escape

$0.3eV$ of E_k

$V = \sqrt{\frac{2E_k}{m}}$

$= 3.2 \times 10^5\ m/s$

$4.97 \times 10^{-19}\ J$

$3.1eV$

$2.0eV$

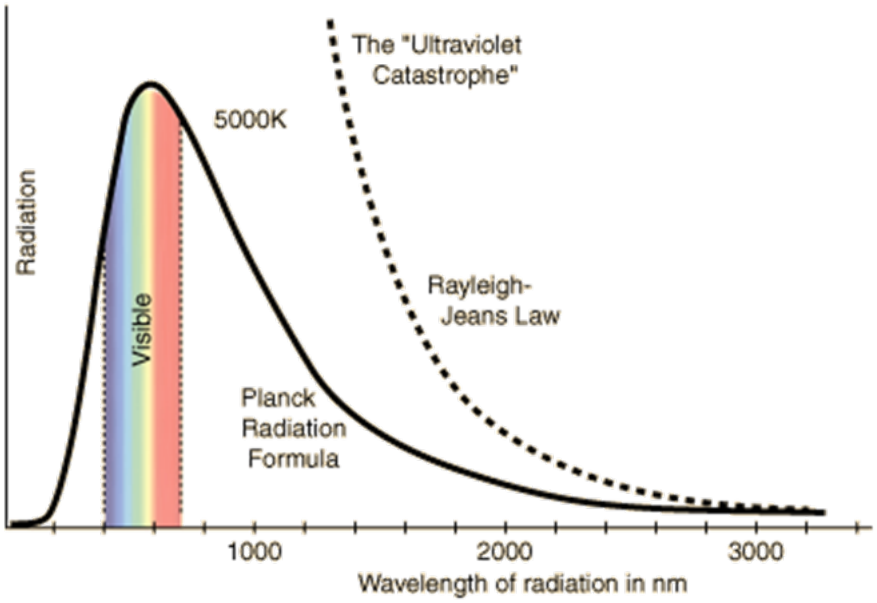
$1.1eV\ E_k$

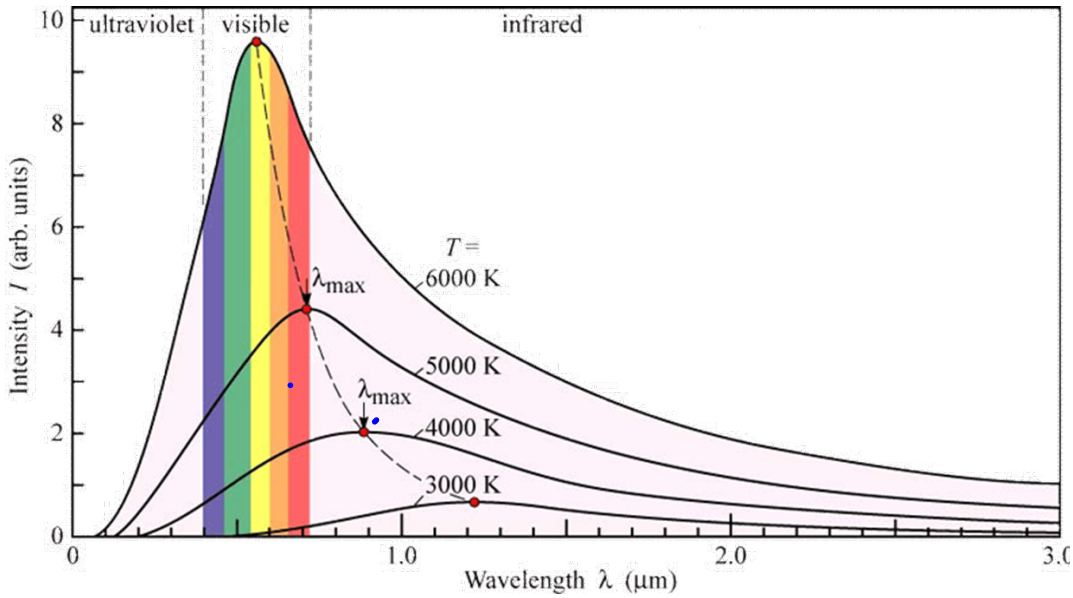
$V = \sqrt{\frac{2E_k}{m}}$

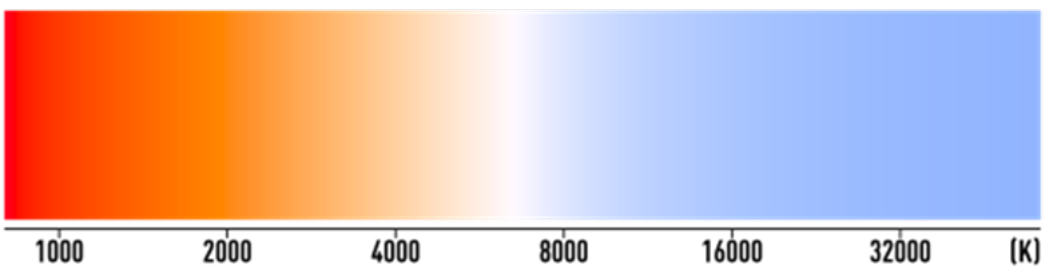
$= 6.2 \times 10^5\ m/s$

More Clues that Light is a particle

Blackbody radiation.

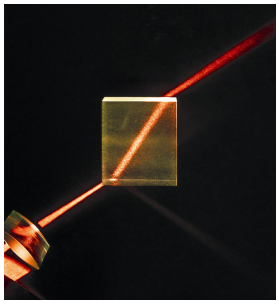


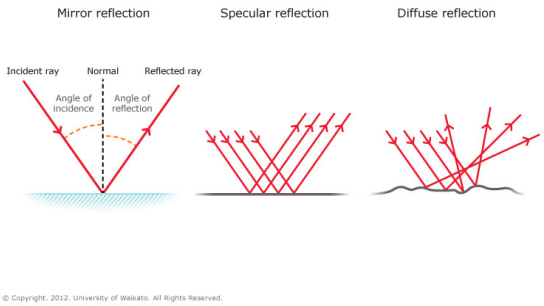




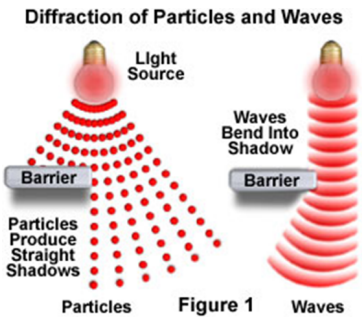
Wave / Particle Duality of Light

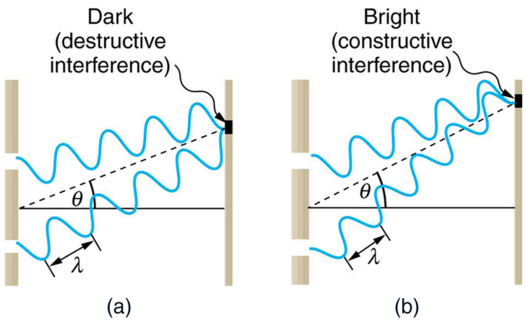
reflection and refraction can be explained by wave model or a particle model of light





Diffraction, Interference and Polarization can only be explained by wave model





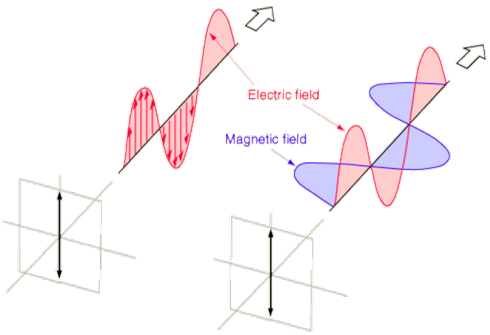
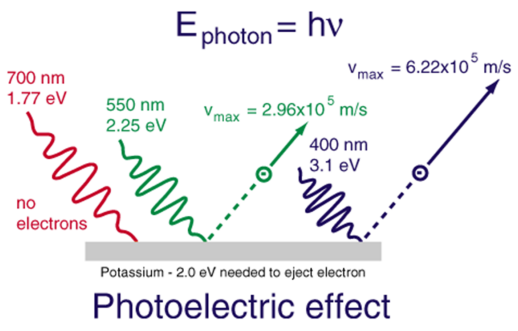
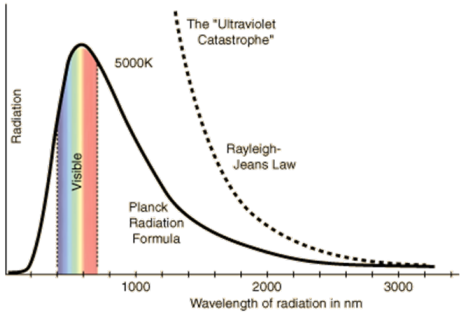


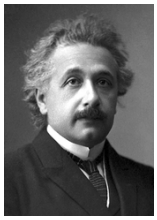
Photo-Electric Effect and Blackbody Radiation can only be explained by particle model





Wave / Particle Duality of Light:

Einstein *"It seems as though we must use sometimes the one theory and sometimes the other, while at times we may use either. We are faced with a new kind of difficulty. We have two contradictory pictures of reality; separately neither of them fully explains the phenomena of light, but together they do."*



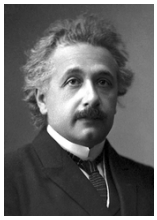
Property	Wave Theory	Particle Theory
Reflection (bouncing)	✓	✓
Diffraction (spreading out)	✓	x
Refraction (bending)	✓	✓
Interference (adding or subtracting)	✓	x
Polarization (orientation)	✓	x
Photoelectric Effect (electron-photon)	x	✓
Blackbody Radiation (emission of photons)	x	✓

Quantum Mechanics

Wave vs Particle Nature of the World

Matter Waves - is an electron a particle or a wave

Wave / Particle Duality of Matter (electrons, protons etc)



Einstein *"It seems as though we must use sometimes the one theory and sometimes the other, while at times we may use either. We are faced with a new kind of difficulty. We have two contradictory pictures of reality; separately neither of them fully explains the phenomena of light, but together they do."*

Property	Wave Theory	Particle Theory
Reflection (bouncing)	✓	✓
Diffraction (spreading out)	✓	x
Refraction (bending)	✓	✓
Interference (adding or subtracting)	✓	x
Polarization (orientation)	✓	x
Photoelectric Effect (electron-photon)	x	✓
Blackbody Radiation (emission of photons)	x	✓

Jun 2019

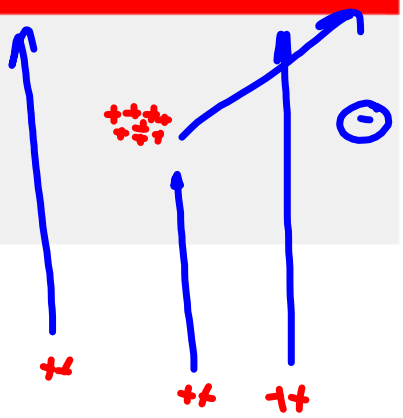
The Standard Model of Particle Physics

The Standard Model
Structure of Protons and Neutrons
Where does Mass come from?

Beyond The Atom:
Video Summary

Name: .....

01. The model of the atom has changed over the past 150 years as new evidence has been found. Draw labelled diagrams for a helium atom using each of these models.

Dalton's model of indivisible balls of matter	Thomson's model using electrons in a positive mass	Rutherford's model using electrons and nuclei
		

02. Rutherford fired alpha particles at gold foil and was surprised by the results.
He developed the nuclear model of the atom because
(a) most of the alpha particles went through.
(b) most of the alpha particles bounced back.
(c) a few of the alpha particles went through.
(d) a few of the alpha particles bounced back.
Explain your choice and make a labelled diagram of Rutherford's experiment.

03. The Large Hadron Collider (LHC) accelerates particles to unprecedented energy levels.
Higher-energy particles are used at the LHC because they can
(a) get closer to each other and probe smaller distances.
(b) create massive particles from the energy.
(c) both of the above.
Explain your choice.

$E^2 = p^2c^2 + m^2c^4$

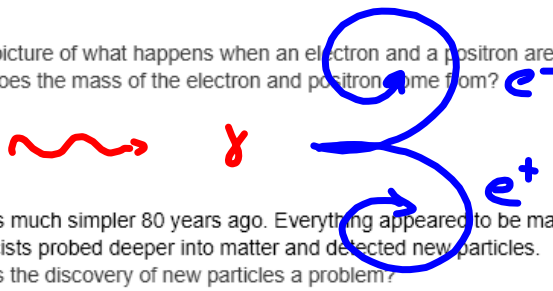
$m = 0$ (photon) $\quad E = pc \rightarrow p = \frac{E}{c}$

$p = 0$ (rel=0) $\quad E = mc^2$ $\quad p = \frac{hf}{c}$

(rest energy, rest mass)

04. The most famous physics equation is Einstein's $E = mc^2$
(a) Explain what each letter in the equation represents, and what the equation means.

(b) Draw a picture of what happens when an electron and a positron are created in a bubble chamber.
Where does the mass of the electron and positron come from?

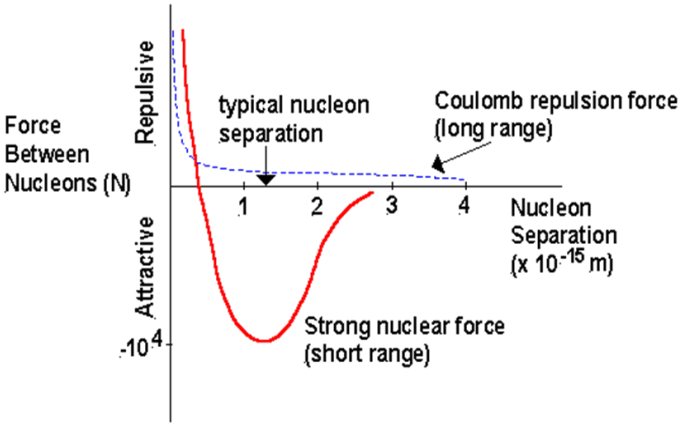


$m = \frac{E}{c^2}$

05. Science was much simpler 80 years ago. Everything appeared to be made of just electron, protons, and neutrons.
Then physicists probed deeper into matter and detected new particles.
(a) Why was the discovery of new particles a problem?
(b) How was it solved?

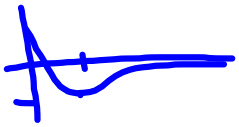
a. → it did not fit the current model
b. → invented even more particles

PERIMETER PI INSTITUTE FOR THEORETICAL PHYSICS


Force
Between
Nucleons (N)
Repulsive
Attractive
-10^4
typical nucleon
separation
Coulomb repulsion force
(long range)
1
2
3
4
Nucleon
Separation
(x 10^-15 m)
Strong nuclear force
(short range)

06. The electromagnetic force pulls opposite charges together and pushes like charges apart. The strong force is different from the electromagnetic force in that the strong force is only attractive and it has
(a) three types of charge and gets weaker with distance.
(b) three types of charge and gets stronger with distance.
(c) two types of charge and gets weaker with distance.
(d) two types of charge and gets stronger with distance.

8



∴

07. The Standard Model describes what is needed to make matter and the forces that hold it together.
(a) Fill in the table for the Standard Model.

	1st Generation	2nd Generation	3rd Generation	Bosons
Quarks				
Leptons				

(b) What is special about the first column?

everyday matter

(c) How are the next two columns different from the first?

heavier, rarer, shorter lifetime

(d) How is the last column different from the other three?

force carrying particles

(e) Compare the periodic table of chemistry and the Standard Model of physics.

P.T. → 100+ elements
S.M. → 12 particles plus 5 force carrying bosons.

08. What particle in the Standard Model is the LHC designed to find? Why is it important?

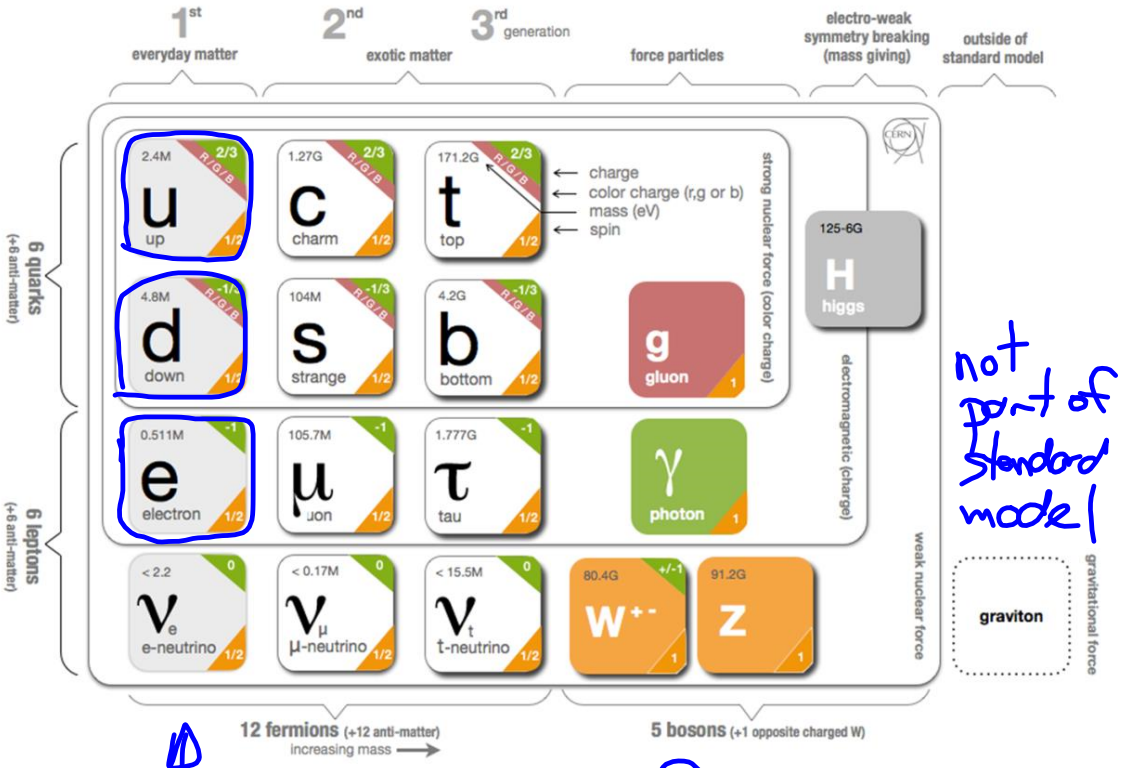
Higgs boson - discovered in 2012.
gives mass to elementary particles.

09. What else might the LHC find? Make a list of all the possibilities mentioned.

Dark matter
Dark energy
New particles - substructure of quarks
Graviton

PERIMETER PI INSTITUTE FOR THEORETICAL PHYSICS

$1B annual expense.



not part of Standard model

force carriers

everyday matter

⟶ heavier, rarer

Up Quark → mass = 2.4M
→ charge = +2/3

mass = 2.4 MeV

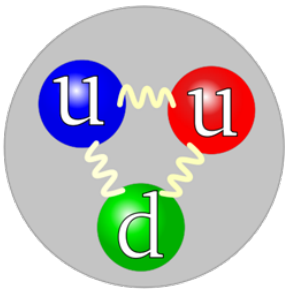
$E = mc^2$

$$m = \frac{E}{c^2} = \frac{2.4\times10^{6}\,eV \times 1.602\times10^{-19}\,J/eV}{(3.0\times10^{8}\,m/s)^2}$$

$$= 4.27\times10^{-30}\,kg$$

The Building Blocks of the Periodic Table

Proton = 2 Up Quarks + 1 Down Quark

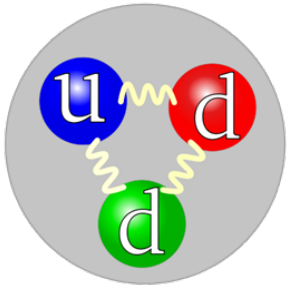


$u +\frac{2}{3}, D -\frac{1}{3}$

$\text{Charge} = 2\left(\frac{2}{3}\right) + \left(-\frac{1}{3}\right)$

$= +1$

Neutron = 2 Downs + 1 Up



$\text{Charge} = 2\left(-\frac{1}{3}\right) + \frac{2}{3}$

$= 0$

Mass - where does it come from?

Proton

Mass of a Proton
= 1,670x10^{-30}kg

Quarks

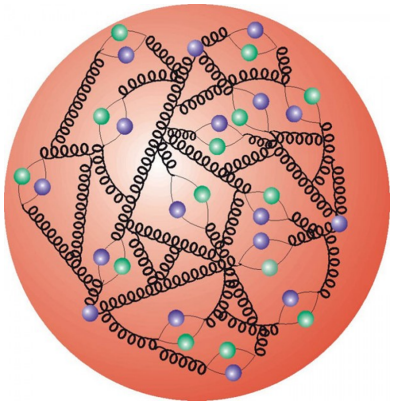
Mass of Up Quark
= 4.27x10^{-30}kg
Mass of Down Quark
= 8.54x10^{-30}kg

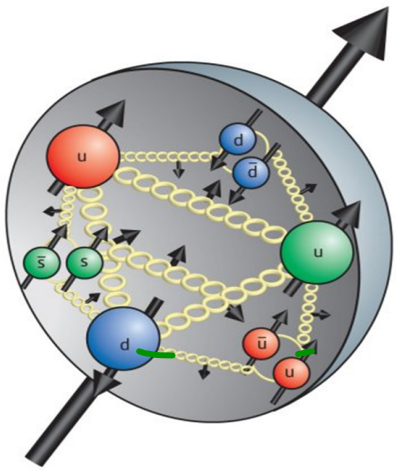
2 Ups and 1 Down
= 17.1x10^{-30}kg

Missing **1,653x10^{-30}kg** of mass?

Where does the missing mass come from?

99% of mass is missing.
all of the missing mass comes from the binding energy of the gluons & kinetic energy of quarks.





Key Takeaways from the Standard Model of Particle Physics

- 3 particles make up the bulk of everyday matter

↑ ↓ Quark, Electron

- recipe for making protons and neutrons

P → 2↑ 1↓ N → 2↓ 1↑

- where does most of the mass of a proton/neutron come from

(gluons) binding energy inside protons & neutrons ~99%

- gravity is not part of the standard model

other 3 forces are part of model

Strong - gluon

Electromagnetic - photons

Weak - W & Z bosons

- eV → J 1.602×10^{-19} J/eV
- eV → mass $E = mc^2$

Jun 2019

Relativity

Special Relativity - Review
General Relativity

Special Relativity Review Questions

1. A high speed spacecraft is travelling at 0.75c (i.e. 75% of the speed of light). If the passengers on the plane measure their time away from earth to be 6 months, how much time has passed for people on earth (based on their clocks)?

$t = t'\gamma$

$t = (6)(1.51)$

$= 9.1 \text{ months}$

$t' = 6 \text{ months}$

$\gamma = \frac{1}{\sqrt{1 - v^2/c^2}}$

$= \frac{1}{\sqrt{1-(.75)^2}}$

$= 1.51$

2. This same high speed spacecraft (still travelling at 75% the speedf of light relative to earth) fires a burst of alpha particles that travel at 75% the speed of light (relative to the spacecraft). What is the velocity of the alpha ray particles relative to a stationary observer on earth c

$V_{AB} = 0.75c$

$V_{BC} = 0.75c$

c

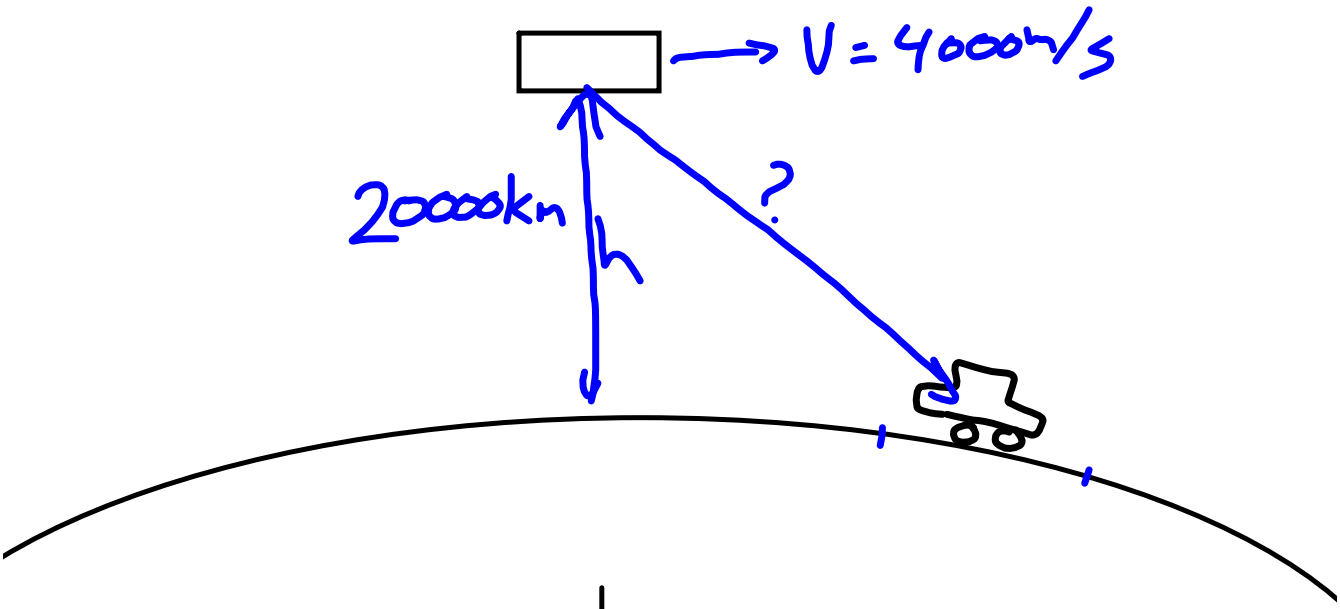
$V_{AC} = \frac{V_{AB} + V_{BC}}{1 + \frac{V_{AB} V_{BC}}{c^2}}$

$V_{AC} = V_{AB} + V_{BC}$

$= \frac{1.5c}{1 + (0.75)(0.75)}$

$= 0.96c$

GPS Satellite Technology



Special Relativity

lose ~7.6μsecs per day (0.000007s)

General Relativity

gain 45.2μsecs per day.

total error in time ~ 38μsecs/day

$d = vxt = c\Delta t$

$\approx 11km.$

Gravity = Acceleration

The stronger the gravitational field – the slower clocks run . . . .

The weaker the gravitational field – the faster clocks run …..