GET1024 / GEC1036

RADIATION

SCIENTIFIC UNDERSTANDING & PUBLIC PERCEPTION

Lecture 01 – Introduction to Module

Chung Keng Yeow

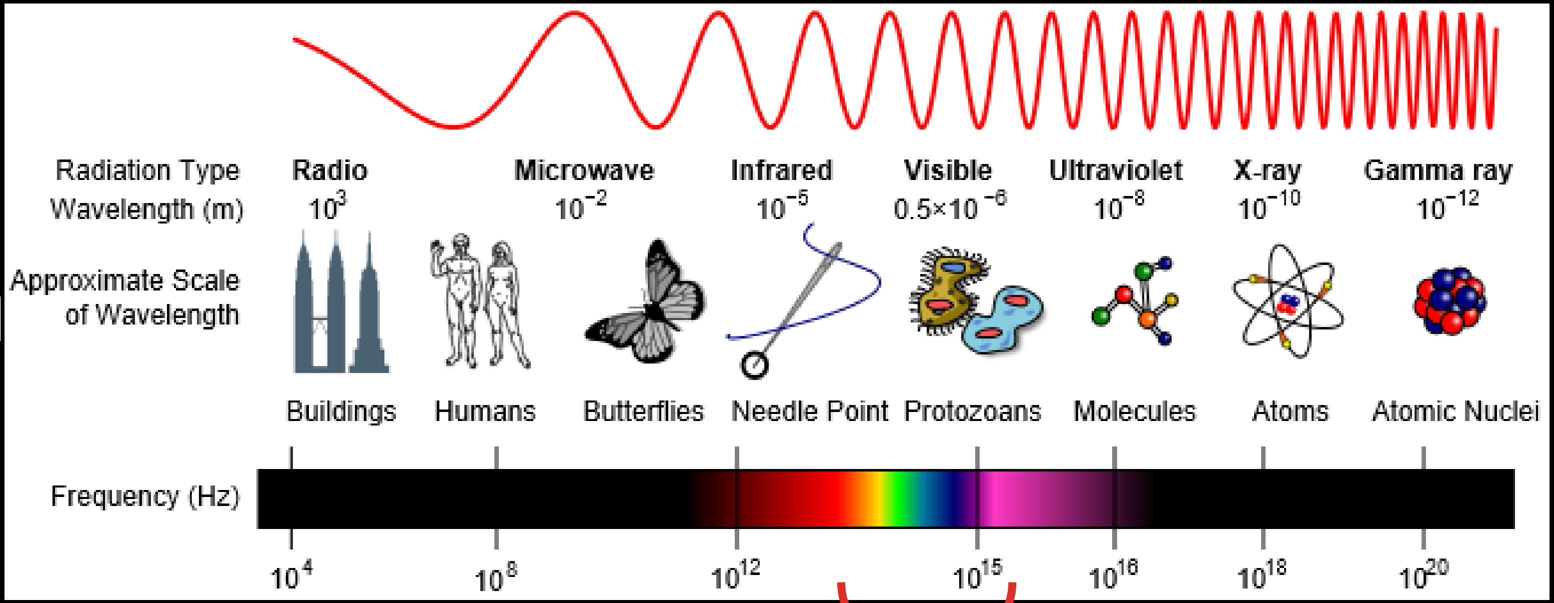
WHAT IS RADIATION?

Energy that comes from a source and travels through some material or through space.

Familiar Examples:

- Radiation from Sun
  - Heat (IR) & Light
- Radiation from mobile
  - Light & Radio waves
- Microwave

[Part of electro-magnetic (EM) spectrum]

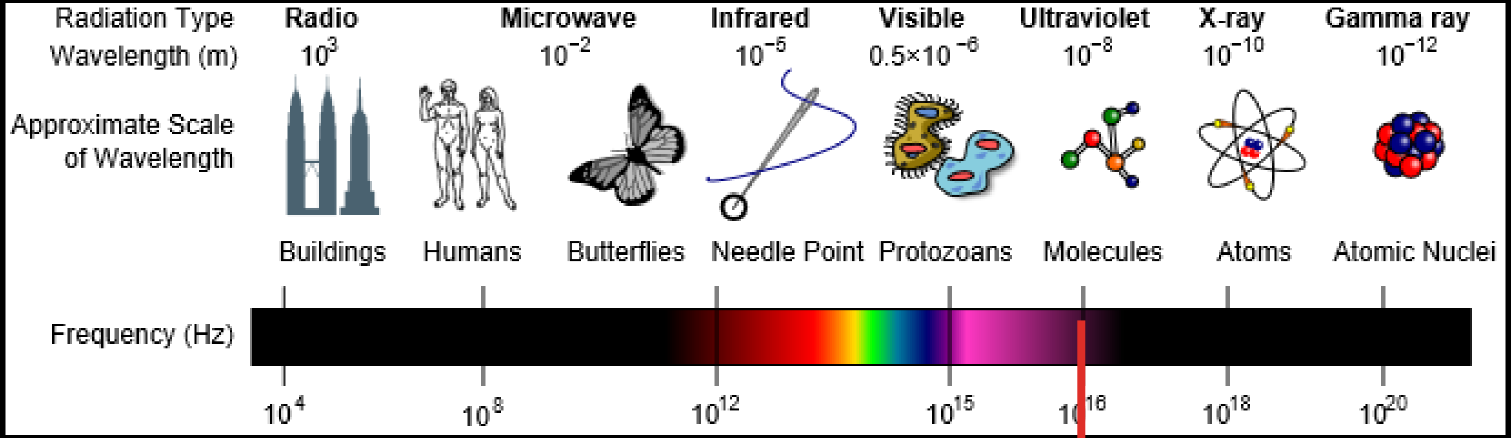


Sensitivity of our eyes

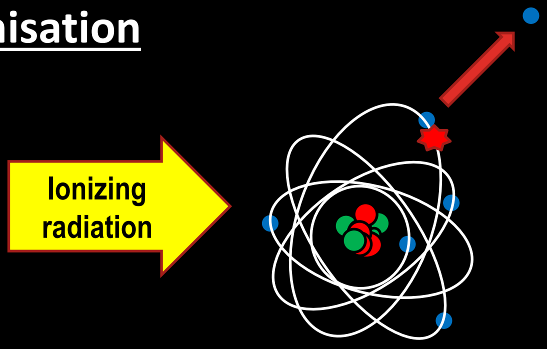
EM spectrum also includes:

- Ultraviolet (UV) light, X-ray & Gamma (γ)-ray

IONISING AND NON-IONISING RADIATION



Ionisation



Non-ionising radiation ← → Ionising radiation

Non-ionising

- Radio wave
- Microwave
- Infrared
- Visible

Ultraviolet

Ionising

- X-ray
- γ-ray

We will study this!

Other ionising radiation:

- electrons
- ions
- protons
- neutrons

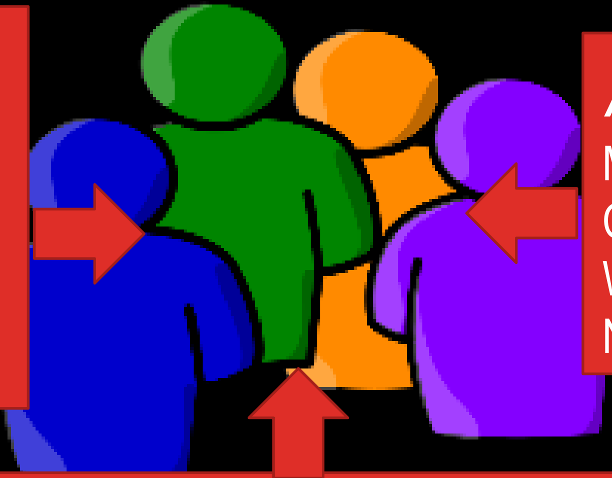
} particles

- cosmic rays → mixture

WHY THIS MODULE?

Ionizing radiation is everywhere!

Natural	mSv*/yr
Radon Gas	2.00
Cosmic Rays	0.27
Terrestrial	0.28
Human body (Internal)	0.40



Artificial	mSv/yr
Medical Procedures	0.53
Consumer Products	0.10
Weapon Tests Fallout	< 0.01
Nuclear Industry	< 0.01

Elective	mSv/yr
One coast to coast Airline Flight	0.02
Watching colour TV	0.01
Heating and cooling with natural gas	0.06
Sleeping with another person	0.01

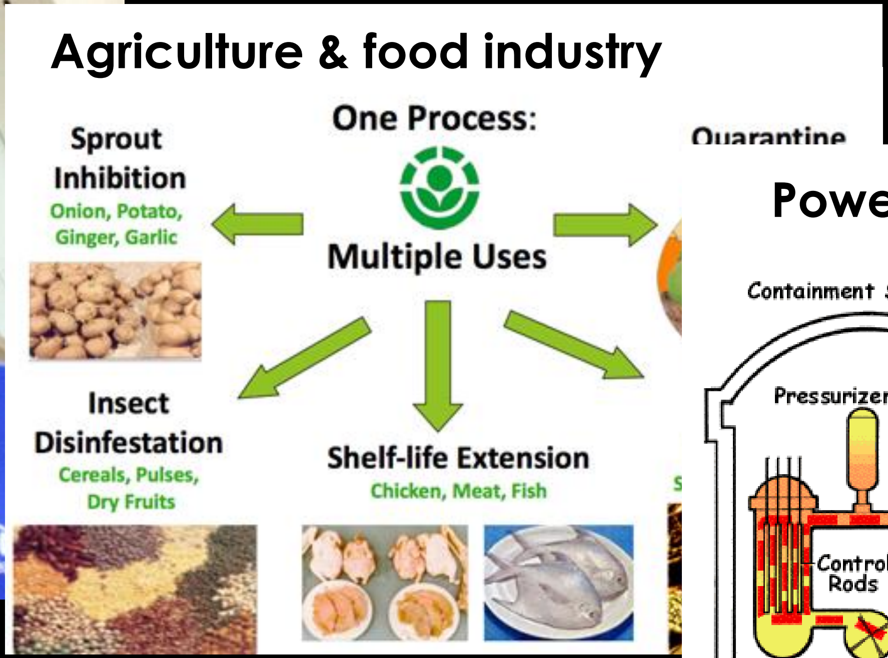
Average annual radiation exposure of a typical American

** Don't worry about the unit mSv yet, you will learn it in due course.*

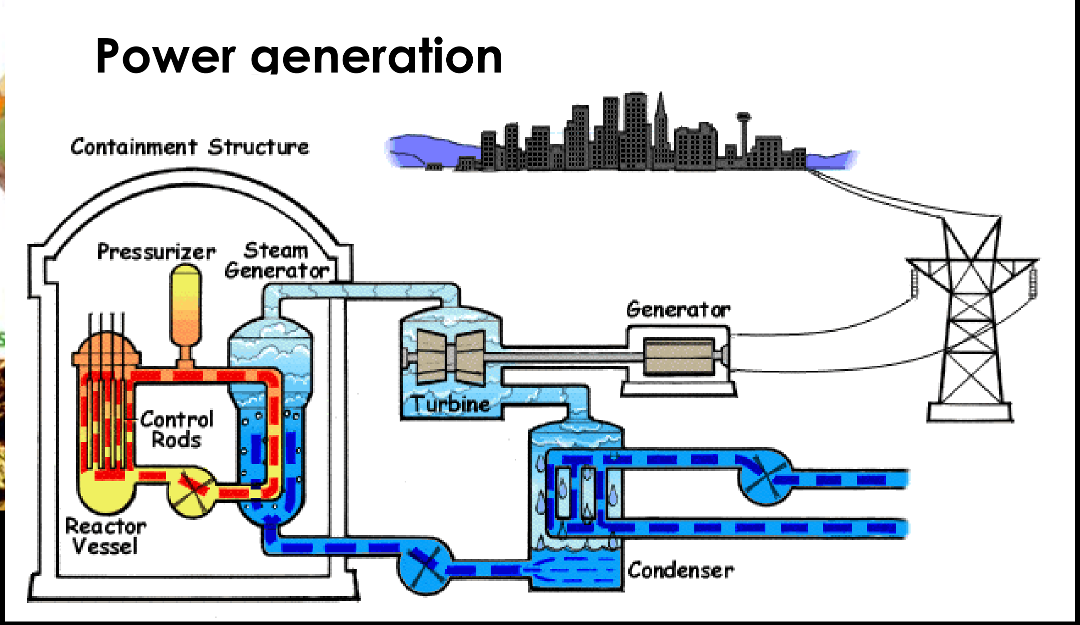
WHY THIS MODULE?

Radiation is increasingly being used, e.g., in

http://images.publicradio.org/content/2010/11/16/20101116_proton-therapy_33.jpg



http://www.foodsng.com/wp-content/uploads/2015/04/irradiated-foods.png



https://en.wikipedia.org/wiki/Pressurized_water_reactor#/media/File:PressurizedWaterReactor.gif

WHAT WE HOPE TO ACHIEVE?

1. Create an awareness on the various aspects of radiation, including its effects and detection, levels of radiation that could be encountered in natural environment, medical or other research equipment, nuclear power plant, etc., and their effects on human health.
2. Students to be able to argue convincingly on the pros and cons of various applications of radiation based on scientific evidence.
3. Equip the students with the essential knowledge to make intelligent assessments on potential uses of radiation or effects of radiation that come with new technologies.

WHAT WILL BE COVERED?

- Basic Science of Radiation
  - Science of Atoms and Molecules and inside the atoms – nucleus, electrons, …
  - Radiation – what they are, types, and how to measure them
  - Effects of radiation on humans
- Applications of Radiation
  - Power generation
  - Medical field
  - Agriculture & Food
  - Industries
  - Arts, Science and Research, etc.
- Public Perception on Radiation

TENTATIVE LECTURE SCHEDULE

Week	Date	Lecture
1	10-Jan-23	Introduction to Module / Modern Physics / Survey
	13-Jan-23	Atoms, Energy Levels and Radiation
2	17-Jan-23	Atomic Nucleus & Radioactivity
	20-Jan-23	Units and Dosage
3	**24-Jan-23**	**Chinese New Year Holiday**
	27-Jan-23	Detection, Measurement and Identification
4	31-Jan-23	Radiation in natural environment
	3-Feb-23	Radiation in everyday life
5	7-Feb-23	Biological Effects of Radiation I
	10-Feb-23	Biological Effects of Radiation II
6	14-Feb-23	Applications of Radiation in Power Production - Nuclear Reactors
	17-Feb-23	Safety of Nuclear Power Plants / Nuclear Accidents
Recess Week		

TENTATIVE LECTURE SCHEDULE

Week	Date	Lecture
7	28-Feb-23	Future Nuclear Power Plants
	3-Mar-23	Nuclear Fuel Cycle and Nuclear Wastes
8	7-Mar-23	Radiation from Nuclear Weapons and Past Tests
	10-Mar-23	**Term Test 1**
9	14-Mar-23	Applications of Radiation in Medicine - Diagnostic Techniques
	17-Mar-23	Applications of Radiation in Medicine - Therapeutic Approaches
10	21-Mar-23	Applications of Radiation in Agriculture & Food Production
	24-Mar-23	Applications of Radiation in Industries & Engineering
11	28-Mar-23	Applications of Radiation in Arts, Science & Research
	31-Mar-23	Public Perception of Radiation 1 - Historical Perspective
12	4-Apr-23	Public Perception of Radiation 2 - Regional & Local
	7-Apr-23	**Good Friday Holiday**
13	11-Apr-23	Summary - Showing some top videos students produced
	14-Apr-23	**Term Test 2**

HOW IS THIS ASSESSED?

- **Two Term Tests** – Tentatively 1-hour paper with 25 **MCQs** [25% each]
- **Group Project** – on one of the given topics – technical and social aspects.
  - 4-minute video [25%]
  - 3000-word report [20%]
- **Participation** [5%]
  - Tutorials
  - Online surveys and quizzes for reading assignments

WHO ARE THIS MODULE?

Chung Keng Yeow
S12-03-12
Tel: 6516 2989
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(Main Lecturer)

- *NUS Physics Department &*
- *Singapore Nuclear Research and Safety Initiative (RI in NUS)*

My research focus

- *Initially on Atomic Physics*
  - *Laser Cooling of Atoms*
  - *Precision Measurements*
- *Now on Nuclear Safety*
  - *Advanced Nuclear Reactors*
  - *Severe Accidents in Current Reactors*
  - *Environmental Radiation, etc.*

Guest lecturers & Tutors from:

- Singapore Nuclear Research & Safety Initiative (SNRSI)
- National Cancer Centre of Singapore (NCCS)

SOME PAST COMMENTS ON THIS MODULE

In person lectures. Very engaging and made me feel a connection to the content being able to see it. It educated me on the true dangers of radiation, and our misconception surrounding it. It got technical, but it had to in order to explain all aspects of radiation, its applications and perception of it. Guest lecturers in who are specialists in their respective fields was a welcome sight too, brought lots of different perspectives to the module.

Funny enough, the reason I love this module is also the reason I hate it. Its broad and intense coverage though a delight to my curious mind and engineering major, is also the bane of my current semester schedule – For it's content coverage when it comes to tests. The module is too intense for a general module. Still, its intensity is needed given my major so it's like this tough love and hate relationship. :D

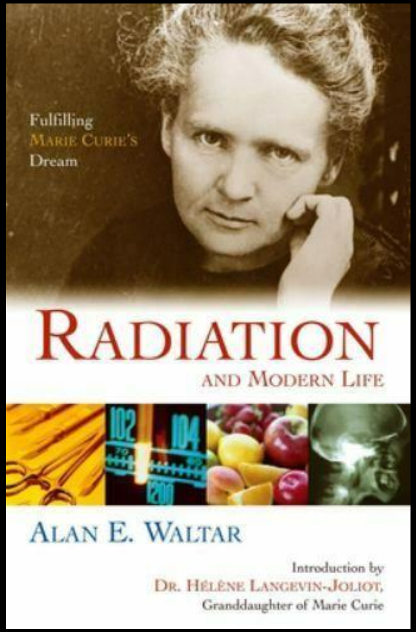
The demonstrations made lectures engaging and interesting. Prof Chung is very knowledgeable in his field and provides background info for many of his lecture material and from his own experiences/visits.

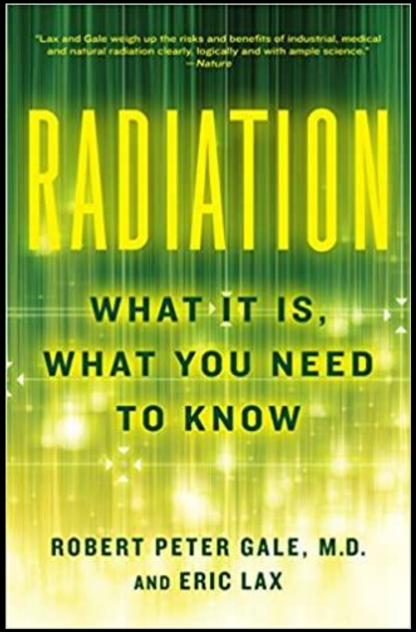
Very thorough in his lectures and content involved. Had demonstrated to students real–life examples of the instruments involved by bringing some to class such as the GM counter and Fiesta Dinnerware.

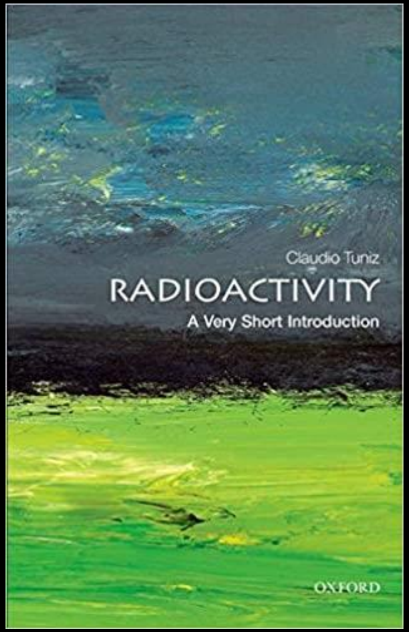
… Despite only having 42 students in the class, he put in insane amount of effort in preparing lecture material, so that the content is very relevant and insightful. He would bring things he talks about in his lectures like lenses that contain radioactive substances and measure their radioactivity live in class. I found these demonstrations fascinating and appreciate his passion and effort in teaching despite having such few students in the lecture hall. He would also constantly revise the content of the course to make it as relevant as possible and would invite many guest lecturers to give lectures as he believes it would benefit us to hear from different perspectives. I can truly feel his passion in radiation and really inspired me to dive deeper into radiation in the future.

REFERENCES

- Some lectures are prepared from "popular science" books such as
  - **Radiation and Modern Life – Alan E. Waltar (Prometheus Book, 2004, ISBN 978-1-59102-250-3)**
  - Radiation : what it is, what you need to know – Robert Peter Gale and Eric Lax (Vintage Books, 2013, ISBN 978-0-307-95020-8)
  - Radioactivity : A very short introduction – Claudio Tuniz (Oxford University Press, 2012, ISBN 978-0-19-969242-2)

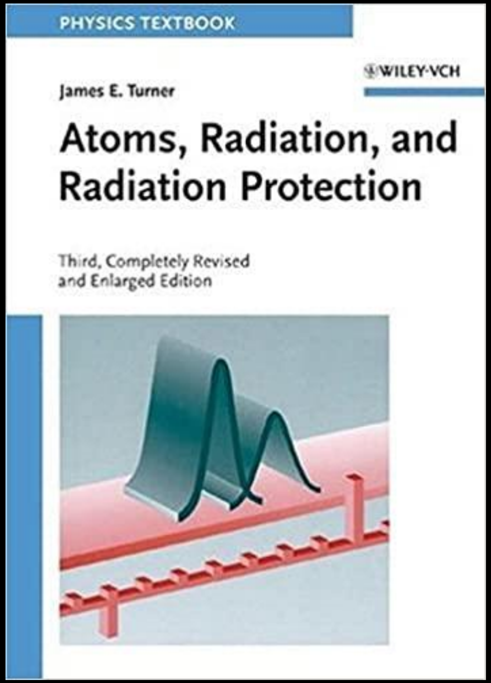


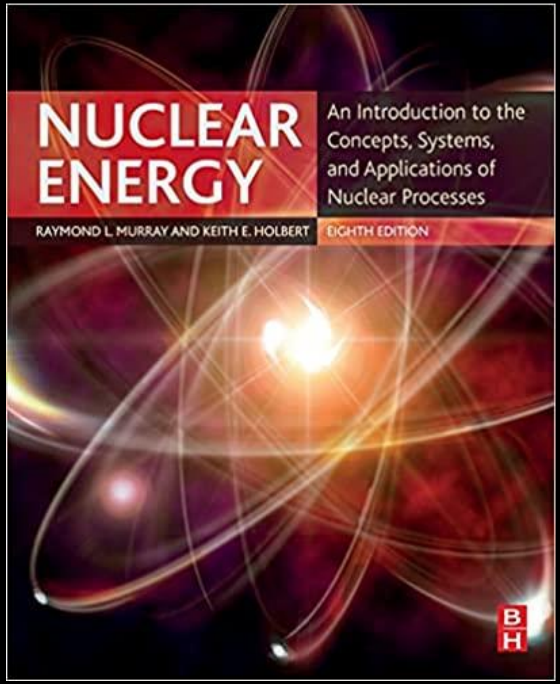




REFERENCES

- If you want more technical books (may download from NUS library)
  - Atoms, Radiation, and Radiation Protection – James E Turner (WILEY-VCH Verlag GmbH & Co., 2007, ISBN 978-3-527-40606-7)
  - Nuclear Energy – Raymond L. Murray and Keith E. Holbert (Elsevier Inc., 2015, ISBN 978-0-12-416654-7)





INTERNET REFERENCES

- For some topics, we will get the latest information from relevant organizations (most of which can be downloaded from the Internet), e.g.,
  - International Atomic Energy Agency (IAEA)
  - United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)
  - International Committee on Radiological Protection (ICRP)
  - World Nuclear Association (WNA)
  - US Nuclear Regulatory Commission (NRC)
  - US Environmental Protection Agency (EPA)
  - Singapore National Environment Agency (NEA)

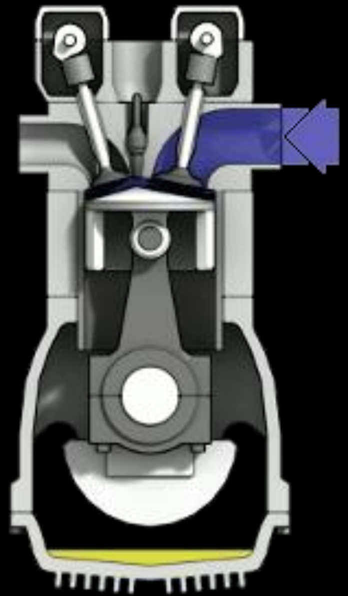
MODERN PHYSICS –
A VERY BRIEF INTRODUCTION

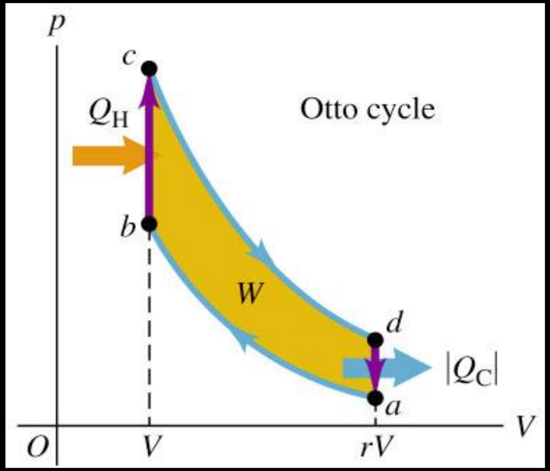
1ST PILLAR OF CLASSICAL PHYSICS

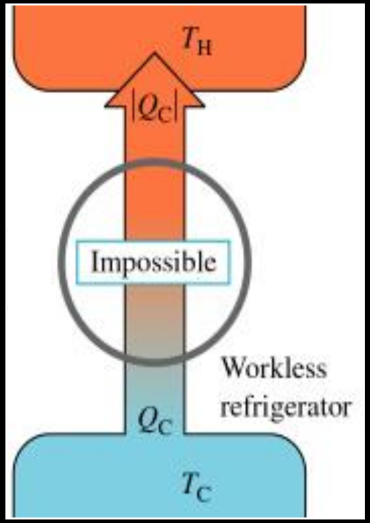
- **Newton's Laws** analyzes the motion of heavenly bodies and objects on earth – build machines, explain natural phenomena, basis for almost all sciences.

2^{ND} PILLAR OF CLASSICAL PHYSICS

- **Laws of Thermodynamics** help us find the most efficient ways to convert energy source to useful work – and explains many phenomena, even the direction of time, and why certain events never happen – introduce concepts of "equipartition of energy", entropy and "quality" of energy.







http://en.wikipedia.org/wiki/File:4StrokeEngine_Ortho_3D_Small.gif

3RD PILLAR OF CLASSICAL PHYSICS

- **Maxwell's Equations** by Maxwell in 1865 unified the electric and magnetic forces and provide a theory for light and other electromagnetic radiation.

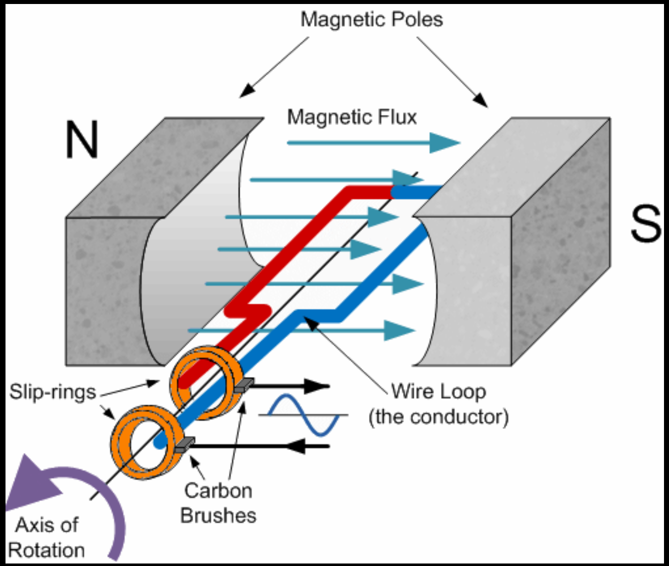
$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{\text{encl}}}{\epsilon_0}$$

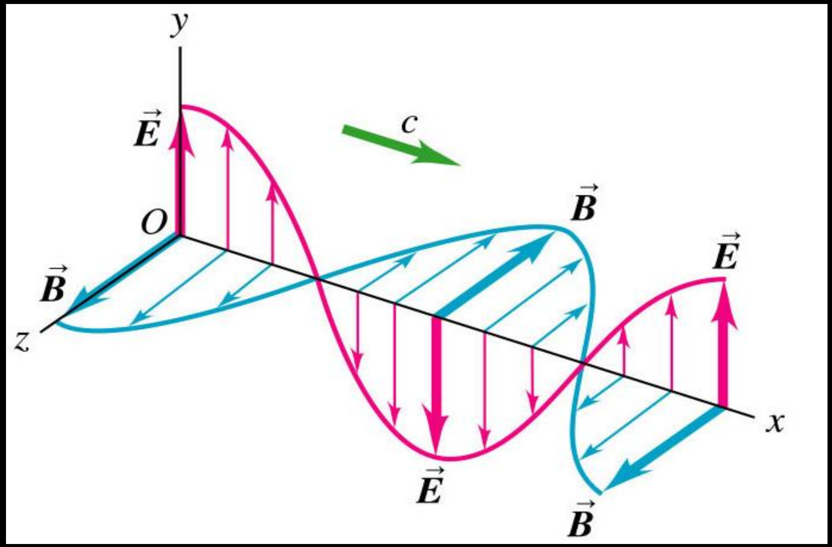
$$\oint \vec{B} \cdot d\vec{A} = 0$$

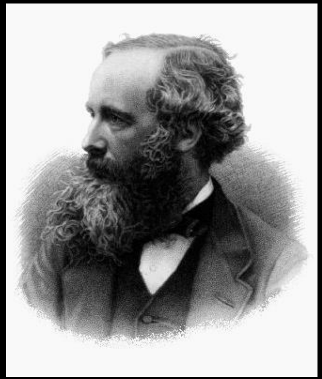
$$\oint \vec{B} \cdot d\vec{l} = \mu_0 \left(i_C + \epsilon_0 \frac{d\Phi_E}{dt} \right)_{\text{encl}}$$

$$\oint \vec{E} \cdot d\vec{l} = -\frac{d\Phi_B}{dt}$$

One form of the Maxwell Equations – *B* is magnetic flux density, *E* is electric field strength – *don't worry about the equations – will not be tested*.



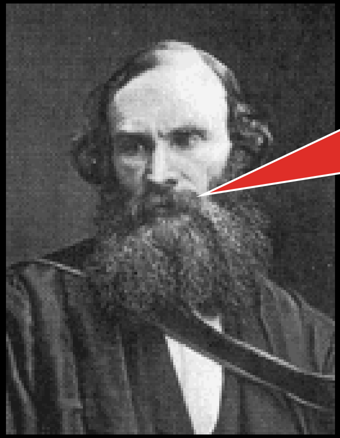




James Clerk Maxwell (1831 – 1879)

END OF PHYSICS?

- Almost every physical phenomenon was understood in terms of these laws – some may be too complicated to be solved analytically but were still just applications of the laws.
- So much so that at the end of 19th century, Lord Kelvin claimed:



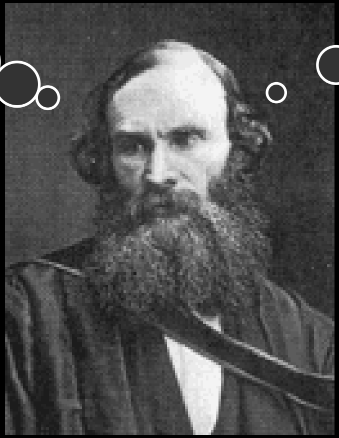
There is nothing new to be discovered in physics now. All that remains is more and more precise measurement.

TWO CLOUDS IN THE HORIZON

- Lord Kelvin did recognize that there were still two unexplained phenomena which he called **two dark clouds** in the horizon.

Michelson-Morley Experiment

Blackbody Radiation



He thought they would go away soon! But … !!!!!

CLOUD 1: MICHELSON-MORLEY EXPT.

- Michelson-Morley experiment which could not detect motion of Earth against ether (medium thought to permeate all space) led Einstein to postulate in 1905 that:

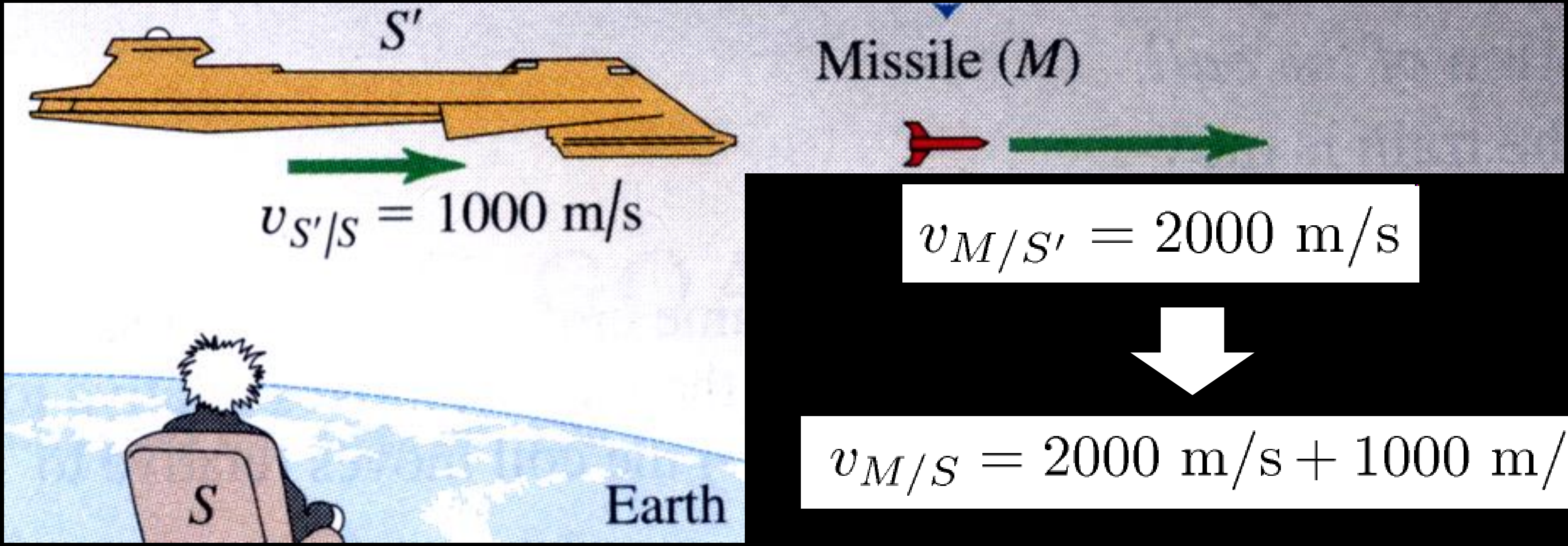
The speed of light in vacuum is the same in all inertial frames of reference and is independent of the motion of the source.

SPECIAL THEORY OF RELATIVITY

RELATIVE VELOCITIES

- A spacecraft moving past the earth at 1000 m/s fires a missile straight ahead with a speed of 2000 m/s relative to the spacecraft. What is the missile's speed relative to earth.

  I think the answer is obvious to all of you …



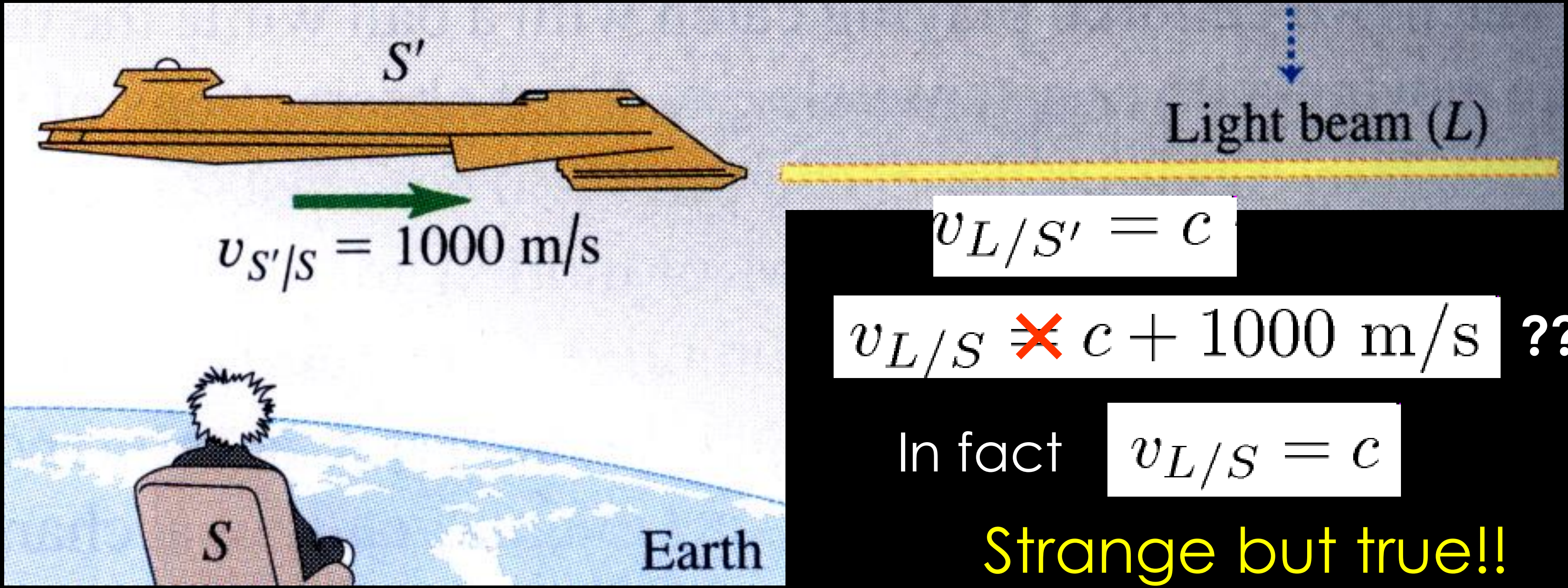
$$v_{M/S'} = 2000 \text{ m/s}$$

$$\Downarrow$$

$$v_{M/S} = 2000 \text{ m/s} + 1000 \text{ m/s}$$

RELATIVE VELOCITIES

- Now suppose the spacecraft turns on a searchlight, pointing in the same direction in which the missile was fired, An observer on the spacecraft measures the speed of light emitted by the searchlight and obtained the value c.
- What will the earth's observer measure as the speed of the light?



$$v_{L/S'} = c$$

$$v_{L/S} \cancel{\neq} c + 1000\ \mathrm{m/s}$$??

In fact $v_{L/S} = c$

Strange but true!!

SPECIAL THEORY OF RELATIVITY

- Space and time are **NOT** absolute!!

- *We need to use Lorentz transformations to transform the coordinates and time between different inertial frames:*

$$
\begin{aligned}
x' &= \frac{x - ut}{\sqrt{1 - u^2/c^2}} \\
y' &= y; \quad z' = z \\
t' &= \frac{t - ux/c^2}{\sqrt{1 - u^2/c^2}}
\end{aligned}
$$

x, *y*, *z* are coordinates of object in one inertial frame (A) while *t* is time measured in this frame. *u* is the relative velocity between frames in the *x*-direction. *x'*, *y'*, *z'* and *t'* are those in another frame (B). *Don't worry about these formulae – will not be tested.*

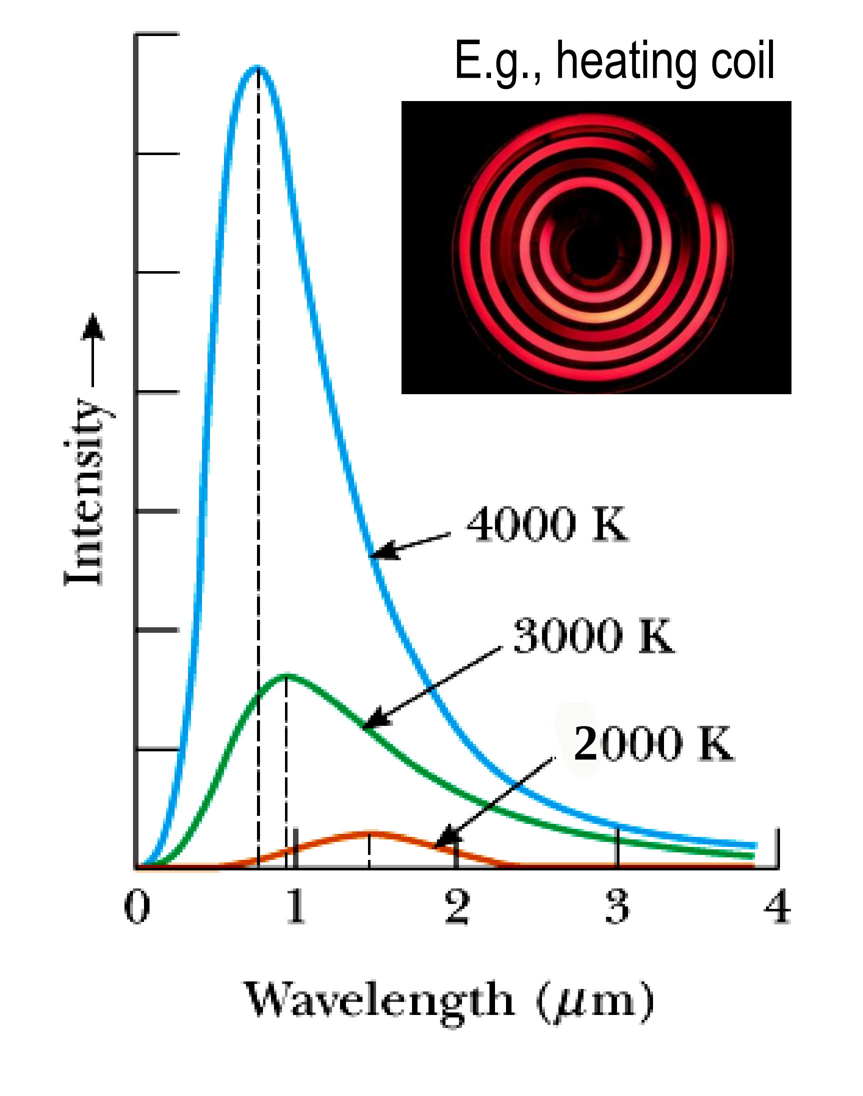
- Leads to interesting effects such as **time dilation** and **length contraction**!

- **Energy** and **mass** are equivalent: $E = mc^2$

We will use this formula in our module!

CLOUD 2: BLACKBODY RADIATION

- Hot bodies emit electromagnetic radiation characteristic of the temperature of the body.
- The total energy per unit area emitted is proportional to T^4, and the peak shifts to the left for higher temperature, i.e., $\lambda_{max} T$ = constant.



CLOUD 2: PLANCK'S HYPOTHESIS

- All attempts to fit data using classical ideas failed miserably.
- Planck, 1900: Proposed that energy of radiation could be **quantized**.

Frequency of EM Radiation

Energy of EM Radiation packet (photon)

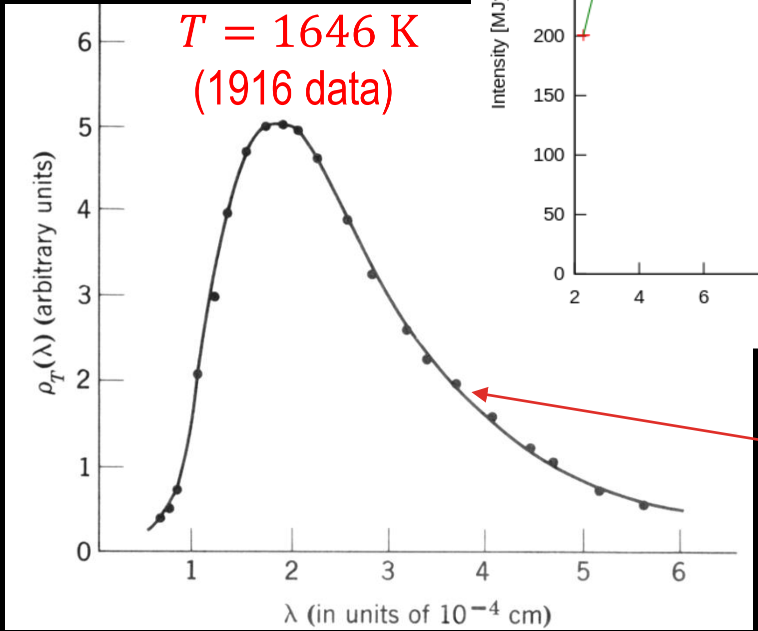
$$E = hf = \frac{hc}{\lambda}$$

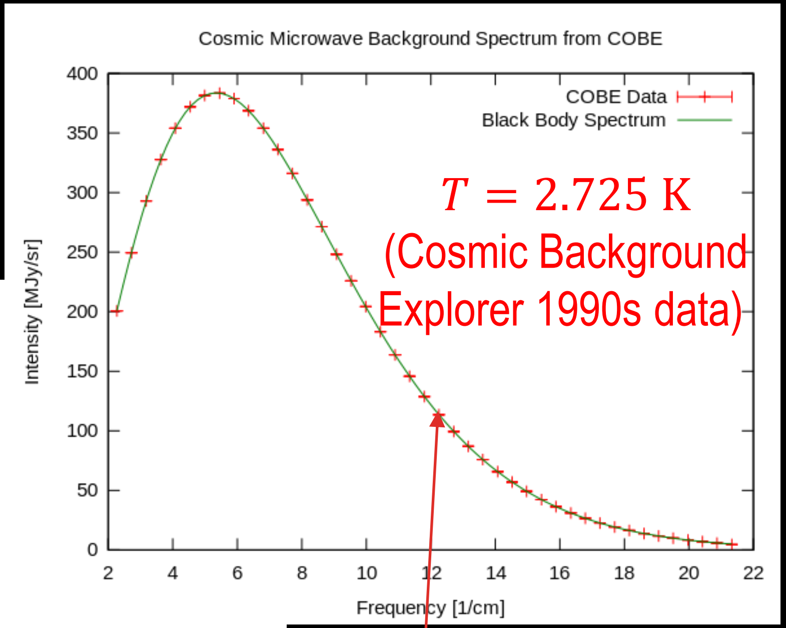
Speed of light

Wavelength of EM Radiation

Planck's constant

QUANTUM MECHANICS





Planck's radiation Law

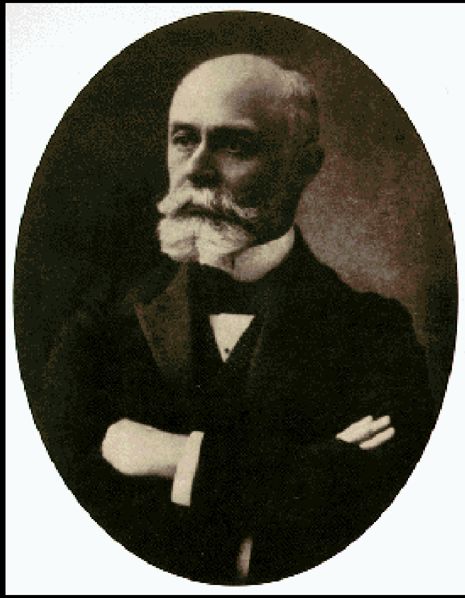
OTHER IMPORTANT DEVELOPMENTS

- It must be a very exciting times around 1900! There were in fact many more "dark clouds"!!
- Unknown rays were discovered – therefore called them

    x-rays (1895) by Roentgen

    α-rays, β-rays and γ-rays (1896) by Becquerel

X-ray image – hand of Roentgen's wife

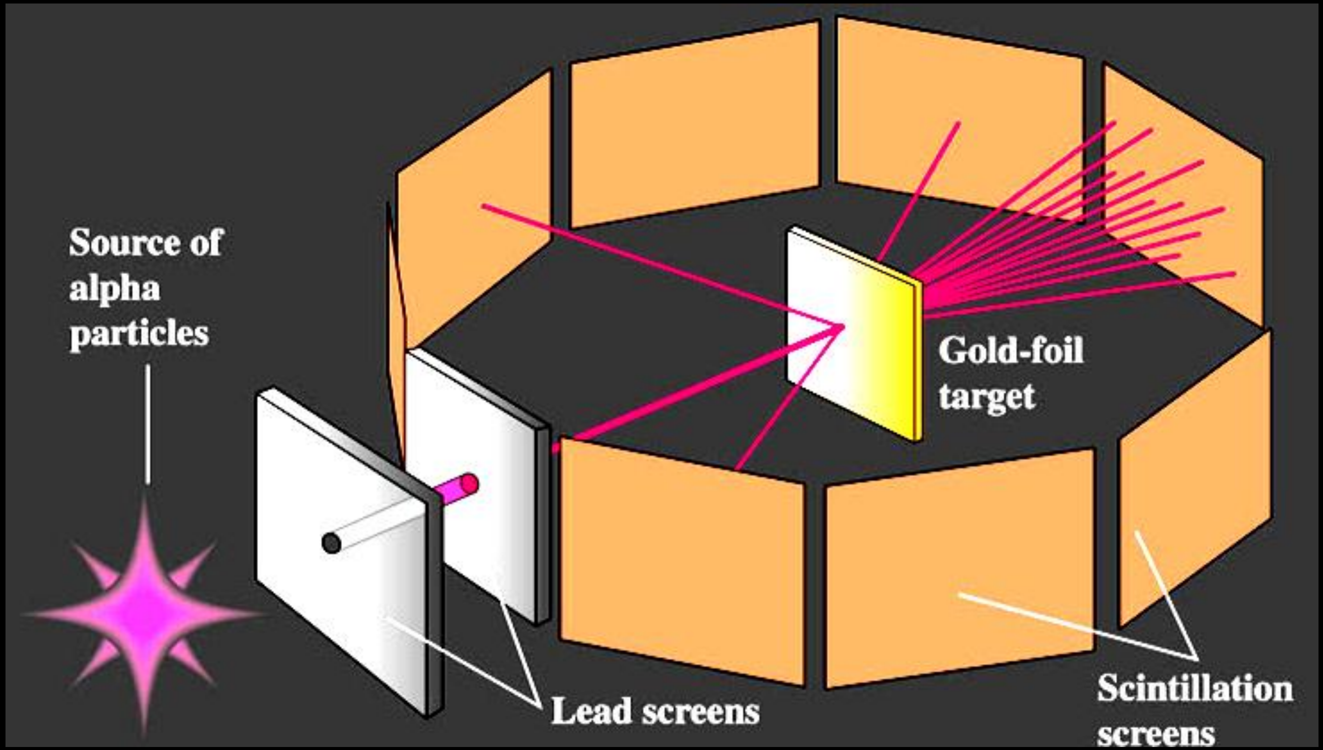


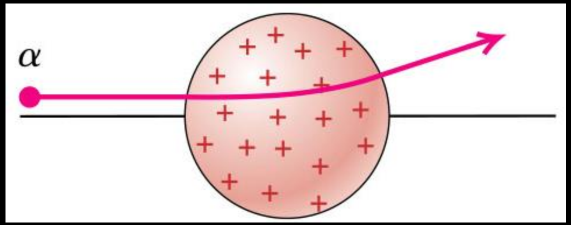
Antoine-Henri Becquerel (l852 – 1908)

Will elaborate in this module

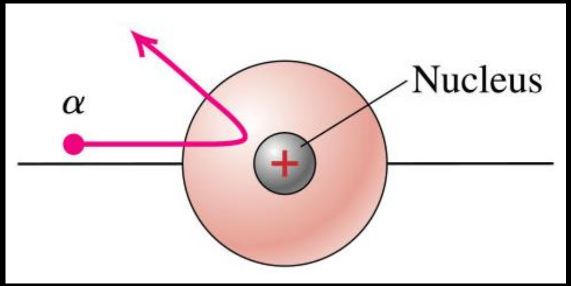
DISCOVERY OF ATOMIC NUCLEUS

- Rutherford's experiment on bombarding gold foil with α-particles, 1911 – only good explanation – a very small nucleus containing almost all the mass of the atom and all its positive charge.





Thomson's model



Rutherford's Model

Will elaborate in this module

EXTRACTING ENERGY FROM NUCLEUS

- Much higher level of energy is involved in nuclear process than atomic process (up to millions time higher)
- Nuclear fission and fusion can both produce energy as demonstrated in nuclear bombs (1940s onwards) and nuclear power reactors (1950s onwards)

Will elaborate in this module

CONCLUDING REMARKS

- Discoveries in the early part of last century with better equipment have often baffled scientists and forced us to abandon some of the 'self-evident' truths and theories.
- Man's ingenuity in his attempts to explain these led to some of the most counter-intuitive theories ever formulated. Amazingly, these theories withstood the most stringent tests over time and had been translated into novel technologies that have the greatest impact on mankind.
- A significant part of the discoveries will be covered in this course though we will concentrate on the applications of these discoveries and especially on controversial ones – nuclear weapons, nuclear power, genetic modification, food irradiation, etc.
- We will begin with the atoms in the next lecture to understand some of the radiation better … and then to the nucleus.