Overview of PHYS 342

- This is an introduction (3 credits) course to modern (20th century) physics
- Prerequisites: PHY 152, PHY251, and Math 166 or equivalent: a solid background of algebra, trigonometry, differential and integral calculus as well as a basic understanding of differential equations.
- Required Materials:

✓ Modern Physics, 3rd Edition, Kenneth S. Krane ISBN : 978-1-118-32464-6, Wiley, January 2012.

✓ Basic scientific calculator for exams

Overview of PHYS 342

http://webphysics.iupui.edu/342/phy342sp16/info.htm

Use Oncourse to send course information

Structure of PHYS 342

A. Lectures: 1 hour 10 mins, interactive, prepare paper, pen and calculator for solving questions!

B. In-class problems: 40 mins, working on problems in groups (not more than 3 students). Each problem is worth 3 points. Each group submits one answer and has one score for all the attendant people of the group. Submit immediately after class.

I will post lecture and in-class problems every week after class.

C. Homework (in textbook, each for 3 points, Homework assigned on Monday by email, due on next Wednesday. 10 days to finish.)

D. Research project : Topic discussion , Project presentation, Research report. (work in groups, 3 person maximum)

Credits of PHYS 342

Grading System	Pts each	Total #	Total pts
In-class problems	3	~30	**90**
Homework	3	~50	**160**
Test 1			**100**
Test 2			**100**
Project			**100**
Comprehensive Final Exam	200	1	**150**
TOTAL			**700**

What is Modern Physics ?

"Modern Physics" refers to physics

1) developed in the 20th and 21th century

2) mostly based on the two major breakthroughs:

theory of relativity and quantum theory

Replace absoluteness with relativity --- even time and space is not absolute!

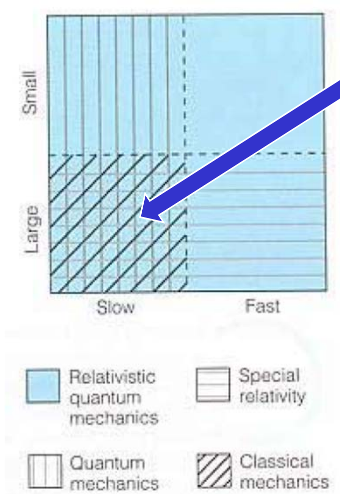
1905 (Special relativity)

1918 (General relativity)

Replace certainty with probability --- any physical quantity is probabilistic!

1900- now (Quantization, Quantum mechanics, Quantum field theory, Quantum electrodynamics, Quantum chromodynamics, string theory etc.)

Physics 2D



In the range of human perception:

Mechanics
Electromagnetism
Thermodynamics

Application:
20^{th} century industry revolution:
Car, train, plane, light bulb, electrical generator, motor, movie, telephone…

Review of Classical Physics

Physics developed before the 20th century mainly based on:

Newton's laws (Phy152)

Maxwell's equations (Phy251)

Thermodynamics (Phy 251)

PHYS 342 In-class Problems (ICP)

- Students work in groups of 1-3 people.
- Problems will be projected on screen.
- Present your calculations and solutions in the paper - specify the problem's ICP# for each problems and write down the full names of group members!
- Ask for teacher's help (not the answer) if you need!
- Submit your work immediately after class.

ICP1 (20 minutes):

Question A

Write down three Newton's laws, and use a couple of sentences to explain them.

Question B

Write down the conservation laws that you think to be most significant ones in classical mechanics.

Question C

Write down the equations of four Maxwell's equations , and use a couple of sentences to explain them (Gauss's laws for B and E fields, Faraday's law, and Ampere's law).

Question D

Write down the first and second laws of thermodynamics, and use a couple of sentences to explain them.

Review of Classical Physics

Newton's 2nd laws

$$\vec{F} = m\vec{a} = m\frac{d^2\vec{x}}{d^2 t} = \frac{d\vec{p}}{dt}$$

$$\vec{p} = m\vec{u}$$

Conservation laws

$$\sum \vec{p}_{initial} = \sum \vec{p}_{final} \text{ when } \vec{F} = 0$$

$$\sum E_{initial} = \sum E_{final}$$

Review of Classical Physics

Maxwell's equations :

$$\oiint_{\partial V} \vec{E}\cdot d\vec{A} = Q(V)/\varepsilon_0$$

Gauss's Law: charge and electric field

$$\oiint_{\partial V} \vec{B}\cdot d\vec{A} = 0$$

Gauss's Law: no magnetic charge

$$\oint_{\partial A} \vec{E}\cdot d\vec{l} = \frac{-\partial \Phi_{B,S}}{\partial t}$$

Faraday's Law: time-changing magnetic fields induce electric fields

$$\oint_{\partial A} \vec{B}\cdot d\vec{l} = \mu_0 I_S + \mu_0 \varepsilon_0 \frac{\partial \Phi_{E,S}}{\partial t}$$

Ampere's Law: magnetic fields can be generated by electric current or time-changing electric fields

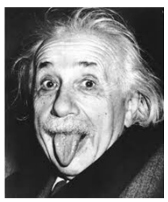
$\mu_0\varepsilon_0 = \frac{1}{c^2}$, vacuum permeability (magnetic constant) and permittivity (electric constant)

Review of Classical Physics

Thermodynamics:

"Classical thermodynamics… is the only physical theory of universal content which I am convinced that, within the applicability of its basic concepts, will never be overthrown."

---- Albert Einstein



Why?

Thermodynamics based on statistics!

The Laws of Thermodynamics: Summary

Zeroth Law

The temperature is introduced via the concept of *thermal equilibrium.*

First Law

Energy conservation in a closed system is used to define both the *heat* Q transferred and the change of *internal energy* of the system ΔU.

Second Law

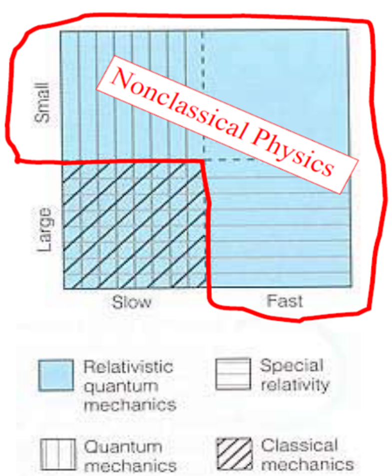
The *entropy* S of an isolated system is defined as a property of the system which has a maximum at equilibrium; i.e.

$$\Delta S \geq 0, \text{ or } S \rightarrow S_{max}.$$

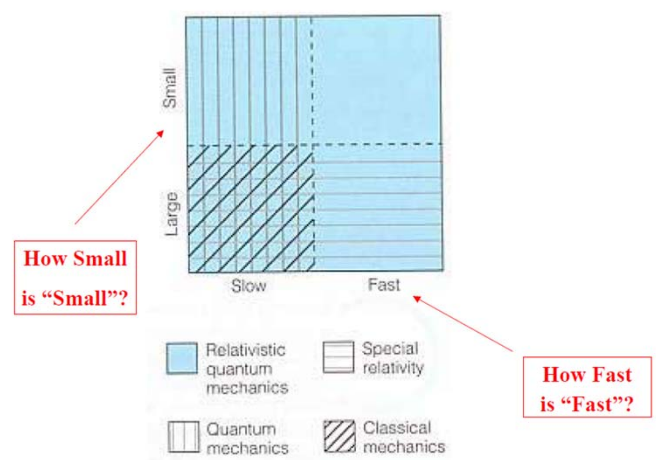
Third Law

The entropy $S \rightarrow 0$ as $T \rightarrow 0$.

Physics 2D

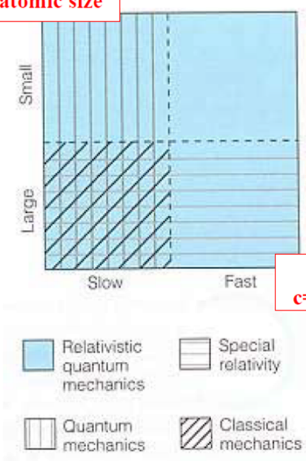


Physics 2D



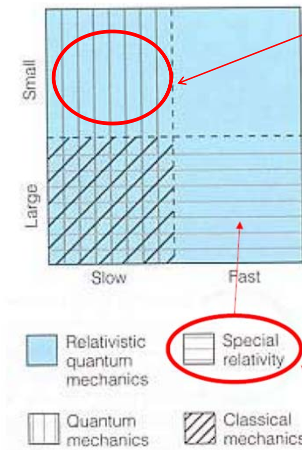
Physics 2D

Small => e.g. atomic size



Fast => v~c
c= the velocity of light

Physics 2D



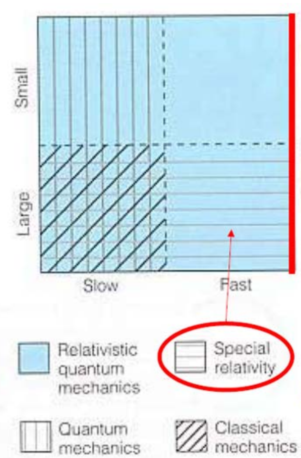
Our Second Topic

Our Third Topic
Subfields in Modern Physics

Cosmology
Condensed Matter Physics
Atomic, molecular, and optical physics
Nuclear physics
High energy (particle) physics
....

Our First Topic

Physics 2D



v<c

Electro-magnetic waves propagate in vacuum at a speed (c) given by:

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = 2.998 \times 10^8 \text{ m/s}$$

Maxwell noted the speed was the same as the measured speed of light in 1865.
Hertz experimentally confirmed light was electro-magnetism in 1887.

Failure of Classical Concept: time

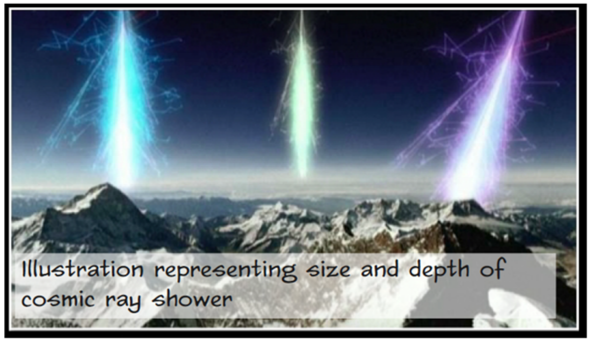
Muon (μ) is an elementary particle

similar to electron, but heavier

$m_\mu = 206.85\, m_e,$ $\quad$ *elctric charge* -1

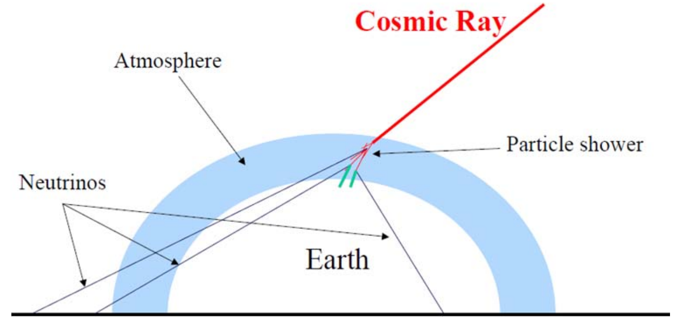
In muon's own frame of reference, its life time is 2.2 microseconds

Failure of Classical Concept: time



Muons are <u>created</u> abundantly in ***elementary particle showers*** in the atmosphere, initiated by energetic ***cosmic rays*** (photons, particles and nuclei).

Failure of Classical Concept: time



A muon is created in the atmosphere 3 km above Earth's surface, heading downward at speed $0.98c$. It survives 2.2 μs *in its own frame of reference* before decaying. (a) *Classically,* how far would the muon travel before decaying and how much longer than 2.2 μs would it have to survive to reach the surface?

Failure of Classical Concept: Muon life time

Example 1.2

A muon is created in the atmosphere 3 km above Earth's surface, heading downward at speed $0.98c$. It survives 2.2 μs *in its own frame of reference* before decaying. (a) *Classically,* how far would the muon travel before decaying and how much longer than 2.2 μs would it have to survive to reach the surface?

Solution

(a) The muon would travel $d = ut = (0.98 \times 3 \times 10^8 \text{ m/s})(2.2 \times 10^{-6} \text{ s}) =$ 647 m. To travel 3 km would require

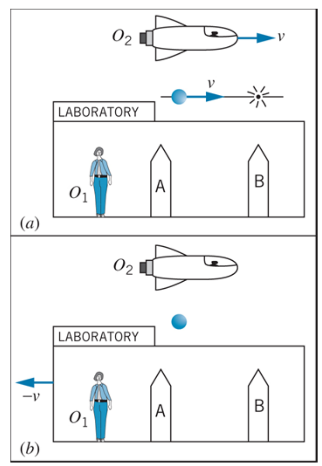
$$t = \frac{d}{u} = \frac{3 \times 10^3 \text{ m}}{0.98 \times 3 \times 10^8 \text{ m/s}} = 10.2\ \mu s$$

An extra 8 μs of "life" would be required. The muon should not reach the surface, for which there are two equivalent explanations: The distance is about five times too far; or the muon survives only about one-fifth the required time.

CONCLUSION: According to Classical Physics,muons should not reach the ground!

BUT THEY DO

Failure of Classical Concept: Space and Time



Muon is generated at A and decay at B.

(a) For O_2 flying reference frame, the lifetime is 2.2 μs. A to B is 647 m.

(b) For O_1 lab reference frame, the lifetime is 10.2 μs, A to B is 3 Km.

Both Time and Space depend on the frame of reference (observer) !
NOT a Newton's world!

Failure of Classical Concept: Velocity

Moving apart; what is the green car's velocity relative to yellow car?

Can be intuitive…

v = 70 km h^{-1}

v = 50 km h^{-1}

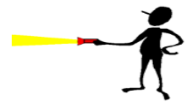
We know the answer intuitively (120 km h^{-1})

In a world determined by Newton mechanics, there is no limitation of the velocity.

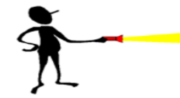
Failure of Classical Concept: Velocity

Same idea with light

From the examples above, we would expect the relative



$c = 3 \times 10^8$ ms^{-1}



$c = 3 \times 10^8$ ms^{-1}

velocity to be $2c = 6 \times 10^8$ ms^{-1}.

This is in fact wrong!

Then what will be the answer?

https://www.youtube.com/watch?v=Ik5ORaaeaME

Let us enter into a Einstein's world,
Next lecture on Wednesday…..

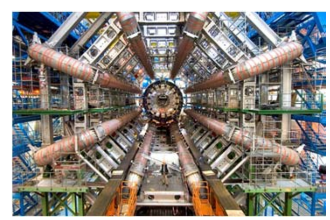
Modern Physics based on Experiments

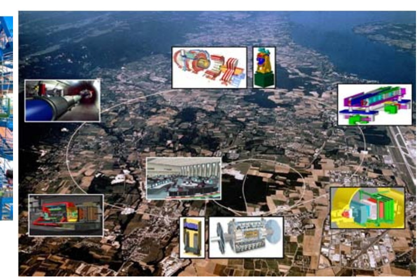
Gravitational Wave

Modern versions of the Michelson-Morley experiment are designed to look for minuscule changes in space and time due to gravitational waves

Modern Physics based on Experiments

Large Hadron Collider (LHC) at the European Organization for Nuclear Research (CERN)

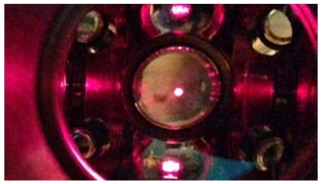


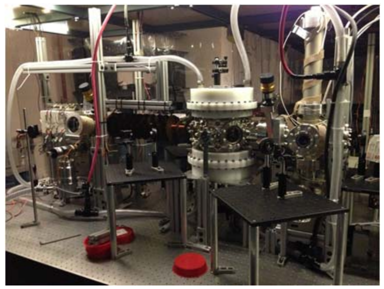


Modern Physics:
Always use experiments to test hypothesis.
No "proved" theory, only "tested" ones!

Modern Physics based on Experiments

Ultracold Atoms at IUPUI





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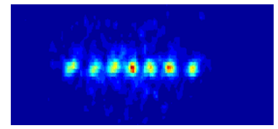
Modern Physics – impact on future

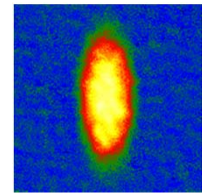
Quantum Matters for Quantum Computers

Trapped Ion



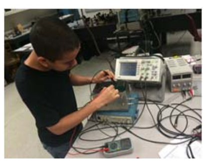
$^{174}Yb^{+}$

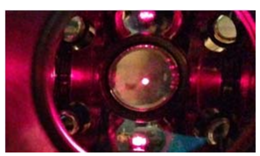
Trapped Atoms



^{6}Li or ^{7}Li

Modern Physics – Undergraduate Research





Tapped Atom and Ion Lab

An undergraduate presentation

https://www.youtube.com/watch?v=ejcaz7wXawY

ICP2 (20 mins): Differential Equations

A principal model of physical phenomena.

The ordinary differential equation:

$$y' = f(x, y)$$

The initial value:

$$y(x_0) = Y_0$$

Find a solution $Y(x)$ on some interval $x_0 \leq x \leq b$. Together these two conditions constitute an "initial value problem".

ICP2 (20 mins):

Question A $y'(x) = \lambda y(x)$ With $y(x_0) = Y_0$,

Question B $y' = 100y - 101e^{-x}, \quad y(0) = 1$

Question C $y'(x) = ay^2$ With $y(x_0) = Y_0 \neq 0$

Homework: Check Email or Oncourse Message!