Programm

- Special Relativity – Galileo and Lorentz transformation.
- Wave - particle dualism of light
- Quantum mechanics postulates. Schrödinger equation and its application (quantum well, tunneling effect).
- Quantum effects: lasers, electron and tunneling microscopes.
- Dynamics of electrons in a solid state. Electrons and holes in
- Semiconducting nanostructures.
- Nucleus. Strong and weak forces
- Fusion and fission reactions.
- Elementary particles.
- The Universe time line
- Elementary modern physics.
  Richard T. Weidner, Robert L. Sells
- Quantum Physics.
  Robert Martin Eisberg
- Elementary Modern Physics.
  Atam Parkash Arya
- My Lecture note given in class
Grading

- Homework .................. 2 points
- Quizzes .................... 2 points
- Three Exams ............... 9 points
- Final Exam ............... 5 points
- Term paper ............... 2 points*

*- optional: if not will be added to exams
Understanding the ideas of each lecture requires the knowledge of the previous lectures.

If you keep up, you won’t end up looking like this the night before the quizzes!
State of Physics *cira* 1895

**Statistical Mechanics**
- 3 Laws of Thermodynamics
- Kinetic Theory

**Electricity & Magnetism**
Maxwell Equations (c 1880)
- Gauss’ Law
- Faraday’s Law
- Ampere’s Law
- No magnetic monopoles

**Mechanics (Gravity)**
Newton’s Laws (c 1640)
1-Law of inertia
2-F=ma
3-Equal and opposite reactions

**Conservation Laws**
- Energy
- Linear & Angular Momentum
RELATIVISTIC PHYSICS

The study of phenomena that takes place in a frame of reference that is in motion with respect to the observer.
Atomic Particles

- Atoms are made of protons, neutrons and electrons
- 99,999,999,999,999% of the atom is empty space
- Electrons have locations described by probability functions
- Nuclei have protons and neutrons

\[ m_p = 1836 \, m_e \]
Atomic sizes

- Atoms are about $10^{-10}$ m
- Nuclei are about $10^{-14}$ m
- Protons are about $10^{-15}$ m
- The size of electrons and quarks has not been measured, but they are at least 1000 times smaller than a proton
What is Light?

- Properties of light
  - Reflection, Refraction
    - A property of both particles and waves
  - Interference and Diffraction
    - Young’s double slits
    - A Property of Waves Only
- Polarisation
  - A Property of Waves Only
Classical Physics

- Light is a wave
- Young’s Double Slit Experiment
- Faraday’s experiments
- Maxwell’s equations

\[ \nabla \cdot E = \frac{\rho}{\varepsilon_0} \]
\[ \nabla \cdot B = 0 \]
\[ \nabla \times E = -\frac{\partial B}{\partial t} \]
\[ \nabla \times B = \frac{1}{\mu_0 \varepsilon_0} \frac{\partial E}{\partial t} + \mu_0 J \]
The Birth of the Quantum

- Max Planck
- The energy contained in radiation is related to the frequency of the radiation by the relationship

\[ E = n hf = nh \nu \]

- \( n \) is a positive integer called the *quantum number*
- \( f \) is the frequency of the oscillation
- A discreet packet of energy, later to become known as “a photon”
Implications of Planck’s Law

- The energy levels of the molecules must be discreet.
- Only transitions by an amount $E=h\nu$ are allowed.
- The implication is that light is discreet or quantised.

These quantum levels are now known as number states.
Photoelectric effect

- When light strikes the cathode, electrons are emitted
- Electrons moving between the two plates constitute a current
Photoelectric Effect

Explanation

- Einstein: the quanta of energy are in fact localised “particle like” energy packets
- Each having an energy given by $hf$
- Emitted electrons will have an energy given by
  $$K_{\text{max}} = h\nu - \phi$$

- Where $\phi$ is known as the “work function” of the material
Properties of matter

- Consists of discreet particles:
  - Atoms, Molecules etc.
- Matter has momentum (mass)
- A well defined trajectory
- Does not diffract or interfere:
  - 1 particle + 1 particle = 2 particles
Wave Properties of Matter

- In 1923 Louis de Broglie postulated that perhaps matter exhibits the same “duality” that light exhibits.
- Perhaps all matter has both characteristics as well.
- For photons,
  \[ p = \frac{E}{c} = \frac{h \nu}{c} = \frac{h}{\lambda} \]
  Which says that the wavelength of light is related to its momentum.
- Making the same comparison for matter we find...
  \[ \lambda = \frac{h}{p} = \frac{h}{mv} \]
Quantum Theory

- Particles act like waves?!
- The best we can do is predict the probability that something will happen.
Quantum mechanics

- Wave-particle duality
  - Waves and particles have interchangeable properties
  - This is an example of a system with complementary properties
- The mechanics for dealing with systems when these properties become important is called “Quantum Mechanics”
The Uncertainty Principle

Measurement disturbs the system
The Uncertainty Principle

- Classical physics
  - Measurement uncertainty is due to limitations of the measurement apparatus
  - There is no limit in principle to how accurate a measurement can be made

- Quantum Mechanics
  - There is a fundamental limit to the accuracy of a measurement determined by the Heisenberg uncertainty principle
  - If a measurement of position is made with precision $\Delta x$ and a simultaneous measurement of linear momentum is made with precision $\Delta p$, then the product of the two uncertainties can never be less than $\hbar/2\pi$

$$\Delta x \Delta p \geq \hbar$$
Virtual particles: created due to the UP

$$\Delta E \Delta t \geq \hbar$$
Higgs boson is “cosmic molasses” – the Holy Grail of particle physics

Interactions with the Higgs Field are theorized to give all the particles their masses

LHC detectors should be able to confirm or disprove initial hints for Higgs at E=115 GeV
جلسه‌ی سوم - نسبیت خاص
On the shoulders of giants

Galileo (1564-1642)

Newton (1642-1727)

Maxwell (1831-1879)
قسایت - دستگاه‌های مختصات اینرستی

قوانین نیوتن براساس دستگاه‌های اینرستی استوار است. این مطلب در قانون اول نیوتن کد شده است.

اگر در یک دستگاه مختصات به یک جسم نیرویی وارد نشود و آن جسم ساکن و یا به حرکت یکنواخت خود را ادامه دهد، آن دستگاه مختصات را اینرستی گویند.

دستگاه‌های اینرستی نسبت به هم حرکت یکنواخت دارند.

اگر دو دستگاه اینرستی که نسبت به هم با سرعت \( V \) در جهت \( S \) و \( S' \) در حرکت باشند، \( x \)
Moving train and platform

- Two inertial frames $S$: $xyz$ and $S'$: $x'y'z'$ - moving train

$\begin{align*}
x &= x' + Vt \\
y &= y' \\
z &= z'
\end{align*}$
Relativity of motion

Consider a ball dropped in a moving train. What happens?

ball's coordinates in $S'$

$x' = 0$, $y' = h - gt^2/2$, $z' = 0$

transformation relates coords

$x = x' + Vt$ or $x' = x - Vt$

$y = y'$

$z = z'$
Falling ball seen from platform

Elapsed time is 1 sec

V = 100 Km/hr
    = 27.8 m/sec
Acceleration

- Newton’s 1st Law: body remains in uniform motion unless acted upon by (net) force
- Non-uniform means $v$ changes (magnitude or direction)
- Changing $v$ over time is acceleration
  
  \[ a = \frac{dv}{dt} = \frac{d^2 x}{dt^2} \]
- $a$ due to gravity = 9.8 m/s$^2$ = $g$ always downward
- Vertical motion on earth
Galilean relativity

- Ball seen from platform follows trajectory for initial velocity in x-direction $u_x = 100$ Km/hr
  $= V$ of train (at time $t=0$)
  [and no initial velocity in y & z directions]
- No force in x direction so $u_x$ of ball unchanged and x increases $x = u_x t$
- Gravity in -y direction, so downward $u_y$ increases and y falls from say $h = 5.0$ m to 0 via $y = h - \frac{1}{2}gt^2$

\[
y = 0 \text{ for } \frac{1}{2}gt^2 = h
\]

So $t = \sqrt{\frac{2h}{g}} = \sqrt{\frac{10.0\text{ m}}{9.8\text{ m/sec}^2}} = 1.0 \text{ sec}$
$\frac{dx'}{dt} = \frac{dx}{dt} - v$, $\frac{d^2 x'}{dt'^2} = \frac{d^2 x}{dt^2}$

$\frac{d^2 z'}{dt'^2} = \frac{d^2 z}{dt^2}$ و $\frac{d^2 y'}{dt'^2} = \frac{d^2 y}{dt^2}$

$F_x = F_{x'}$, $F_y = F_{y'}$, $F_z = F_{z'}$

$\overrightarrow{F} = \overrightarrow{F'}$
پس هنگامی که از یک دستگاه اینرسی به یک دستگاه اینرسی دیگر می‌رویم معادله‌های حركة تغییر نمی‌کند و به عبارت دیگر در تبدیلات گالیله قوانین نیوتن ناوردای می‌مانند.

ناظر‌های پیوسته به دستگاه‌های اینرسی مختلف یک پدیده را یک طور تعبیر می‌کنند. هیچ پدیده‌ی مکانیکی نمی‌تواند بین سیستم‌های اینرسی تفاوت بگذارد.

بنابراین به وسیله‌ی هیچ آزمایش مکانیکی نمی‌توان ثابت کرد که یک دستگاه اینرسی در حال سکون است و بقیه نسبت به آن حركة یکنواخت دارند.
اما معادلات ماکسول تحت این تبدیلات تغییر شکل می‌دهند.

پس می‌توان با استفاده از پدیده‌های الکترومغناطیسی بین دستگاه‌های اینرسی مختلف تمايز قائل شد.
• Swimmer goes distance L and back in river flowing at velocity $u$ relative to shore - forward at $c+u$ and back at $c-u$ ($c =$ speed in still water)

$$\text{Time elapsed} = \frac{L}{c+u} \text{ forward} + \frac{L}{c-u} \text{ back}$$
Swim time calculation

\[
\text{total time} = \frac{L}{c+u} + \frac{L}{c-u} = L \left( \frac{1}{c+u} + \frac{1}{c-u} \right)
\]

\[
= L \left( \frac{c-u}{(c+u)(c-u)} + \frac{c+u}{(c+u)(c-u)} \right)
\]

\[
= L \frac{2c}{(c^2-u^2)} = 2 \frac{L}{c} \left( \frac{1}{1-\frac{u^2}{c^2}} \right) > 2 \frac{L}{c}
\]
Swimmer crosses river directly, perpendicular to flow 
Must swim against flow - negative $u$ in x direction 
& +or- some $v_y$

Combine to form c
Adding swimmer velocities

\[ c^2 = v_y^2 + u^2 \]
\[ v_y = \sqrt{c^2 - u^2} \]

Time to cross is also \( >2L/c \) but \(<\) parallel crossing time
•Parallel swimmer takes longer than lateral swimmer
•Both take longer than swimming with no current
•Apparent speed of lateral swimmer from shore (S frame) is slower than speed that would be seen from boat moving with current
•Swimmer can be wave pulses on moving water - results of dropping rock from boat moving with u
•What if light were the swimmer and ether the river?
Laws of Physics are Invariant

• Newton’s 2nd Law is unchanged in all inertial frames
• What about light - EM waves?
• Maxwell’s waves - Review
• T. Young (1801) showed that light behaves like a wave - it undergoes interference
• Mechanical waves - water, sound, vibrating strings and solids - are disturbances of a medium that propagate due to elasticity of the medium
• If light is a wave, what is waving?
• Maxwell (~1860) theorized that light is an EM wave
Michelson-Morley Experiment (1887)

\[ t_2 = \frac{2L_2}{c}\sqrt{1 - \frac{u^2}{c^2}} \]

\[ t_1 = \frac{2L_1}{c}(1 - \frac{u^2}{c^2}) \]

half-silvered mirror

ether
• $c = 3.0 \times 10^8 \text{ m/s}$

• $u_{\text{earth}}$ = orbital speed (relative to ether) = ?
  – $R \sim 150 \times 10^6 \text{ Km} = 1.5 \times 10^{11} \text{ m}$
  – $T \sim 365 \text{ days} \times 24 \text{ hr/day} \times 3600 \text{ s/hr} = 3.2 \times 10^7 \text{ s}$
  – $u \sim 2\pi R/T \sim 3 \times 10^4 \text{ m/s} = 30 \text{ Km/s}$

• $u/c \sim 10^{-4}$ $\ll$ 1 and $(u/c)^2 \sim 10^{-8}$

• For $L_1 = L_2$, have $t_1 - t_2 = \frac{2L}{c(1 - (u/c)^2)} - 2L/c\sqrt{1 - \frac{u^2}{c^2}} \sim (L/c)(u/c)^2$

ائيشتين و ديگران عدم وجود اتري را مدعی شدندا.
Special Relativity

- Einstein (1905) required
  - Laws of Physics are independent of inertial frame or one can not detect absolute motion
  - Speed of light (c) is independent of the motion of the source or c is velocity of EM wave in any inertial frame

- How can these 2 innocent requirements be compatible?
  - Construct a light clock