Block 1 - Modern Physics and Relativity

Chapter 1 - Crisis of Classical Physics in Late 1800s

Introduction

Classical mechanics, thermodynamics, electromagnetism: Newton, Boltzmann, Maxwell, Rayleigh, Jeans, Ampere, Hertz, Huygens, Young

↓

Crisis: couldn't explain observations, particularly regarding EM waves.

↓

Modern physics, quantum mechanics, special relativity: Planck, Millikan, Thompson, Einstein, Rutherford, Bohr, Feynman

- Some problems
  - -> Blackbody radiation: Maxwell couldn't explain, Planck postulated energy quanta.
  - -> Photoelectric effect: Maxwell couldn't explain, Einstein postulated light particles with Planck's energy quanta.
  - -> Discrete line atomic spectra: Bohr extended quantization to angular momentum which began quantum mechanics
  - -> Constant c: Einstein's Special Theory of Relativity

- EM spectrum

  Gamma X Ultraviolet Vis Infrared Micro Radio

  -> $\lambda f = c = 3 \times 10^8$ m/s

→ m_s

- Electron spin quantum number
- $\pm\frac{1}{2}$
- Relates to spin direction up/down

$S_z = m_s \hbar \quad (m_s = \pm\frac{1}{2})$

- Quantum rules

For any electron transition:

→ Δn = anything

→ $\Delta l = \pm 1$

→ $\Delta m_l = 0, \pm 1$

- Naming convention for shells and subshells

→ $l = 0$: s

→ $l = 1$: p

→ $l = 2$: d

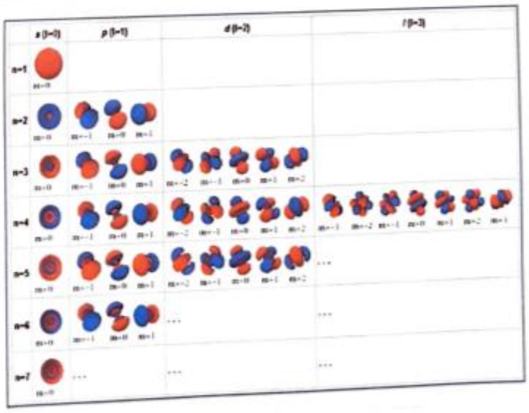
→ $l = 3$: f

→ $l = 4$: g

eg) $n=3, l=2$ ⇒ 3d orbital

$n=2, l=0$ ⇒ 2s orbital

$n=6, l=4$ ⇒ 6g orbital



PREVIEW

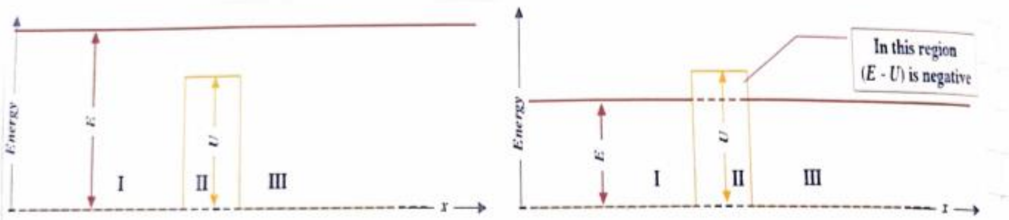
123tutors

123tutors.co.za/notes

The SE For Barrier Penetration/Scattering

- Basic properties
  - → Particles travelling left to right
  - → x is position
  - → y is total energy E / potential energy U

- Systems:
  - → 1: $E > U$
  - → 2: $E < U$ (classically ⇒ no penetration)



- Boundary conditions
  - → similar to finite well

- Solutions with SE
  - → region 1

$$\frac{\partial^2 \psi}{\partial x^2} = -\frac{2mE}{\hbar^2}\psi \; ; \; E > 0 \quad \Rightarrow \quad \psi = Ae^{ikx} + Be^{-ikx} \; ; \; k = \frac{\sqrt{2mE}}{\hbar}$$

  - → region 3

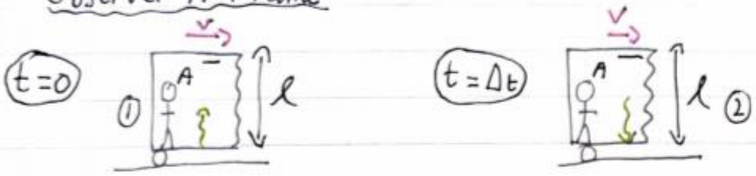
$$\frac{\partial^2 \psi}{\partial x^2} = -\frac{2mE}{\hbar^2}\psi \; ; \; E > 0 \quad \Rightarrow \quad \psi = Fe^{ikx} + Ge^{-ikx} \; ; \; k = \frac{\sqrt{2mE}}{\hbar}$$

Time Dilation

Two events that one observer interprets as occurring in the same place at different times may occur at different places at different times for another observer that is in relative motion to the first. Consider a photon emitted from the floor of a carriage, reflected and detected again at the floor:

Event 1 Event 2

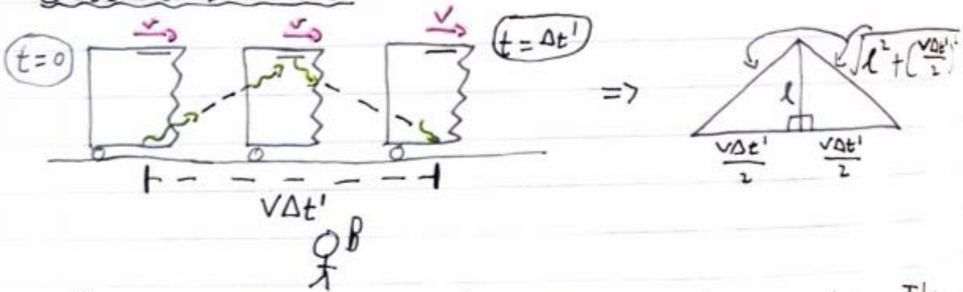
Observer A Frame



A sees the events occurring at the same place and measures the time between them – the "proper time" – to be:

$$\Delta t = \frac{2l}{c}$$

Observer B Frame

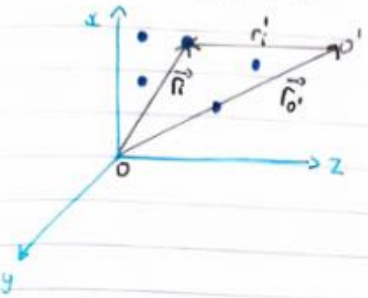


According to B, the events do not occur in the same place. The distance between events is $v\Delta t'$, and so the photon travelled a distance $2\sqrt{l^2+(\frac{v\Delta t'}{2})^2}$ which must equal $c\Delta t'$

1.6) General Motion - 8

Motion of COM - 8

Take a system of many particles:



O' fixed to body

1 particle: $\vec{F_i} = \vec{F}_{i,ext} + \sum_{j=1}^{N} \vec{F_{ij}} = m_i \vec{a_i}$

All particles: $\sum_{i=1}^{N} m_i \vec{a_i} = \sum_i \vec{F}_{i,ext} + \underbrace{\sum_i \sum_j F_{ij}}$ — Can reverse summations (proof: expand) — ①

$$= \frac{1}{2}\left(\sum_i \sum_j \vec{F_{ij}} + \vec{F_{ji}}\right)$$
$$= \frac{1}{2}\left(\sum_i \sum_j \vec{F_{ij}} - \vec{F_{ij}}\right)$$
$$= \vec{0}$$

So forces within the system cancel.

Now define $\vec{r_{cm}} = \dfrac{\sum_{i=1}^{N} m_i \vec{r_i}}{\sum_{i=1}^{N} m_i}$ and set $\vec{r_{o'}}$ to be $\vec{r_{cm}}$ so $\vec{r_i} = \vec{r_{o'}} + \vec{r_i}'$

$\vec{r_i} = \vec{r_{cm}} + \vec{r_i}'$

Then ① becomes $\dfrac{d^2}{dt^2} \sum_{i=1}^{n} m_i(\vec{r_{cm}} + \vec{r_i}') = \dfrac{d^2}{dt^2}\left(M\vec{r_{cm}} + \underbrace{\sum_{i=1}^{N} m_i \vec{r_i}'}_{=0}\right) = \vec{F}_{tot,ext}$

$=0$ because $\vec{r_i}'$ is now COM position measured relative to COM

So:

$$\frac{d^2}{dt^2} M \vec{r_{cm}} = \vec{F}_{tot,ext}$$

(Looks like force acts at com point.)

($\vec{r_{cm}}$ independent of co-ord sys.)

$M\vec{a}_{...}$

PREVIEW

123tutors

123tutors.co.za/notes

Damped Harmonic Motion - 37

- New DE

$F = m\ddot{x}$, $F_{restoring} = -kx$, $F_{retarding} = -c\dot{x}$

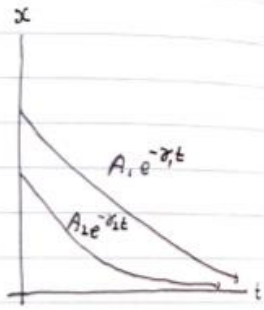
$m\ddot{x} + c\dot{x} + kx = 0$

- Solution

Try $Ce^{qt} = x$: works iff:

roots: $q = -\gamma \pm \sqrt{\gamma^2 - \omega_0^2}$; $\gamma = \frac{c}{2m}$ $\omega_0^2 = \frac{k}{m}$

- $\gamma^2 > \omega_0^2$: overdamping
  - → real negative roots
  - → non-oscillatory, decays exponentially
  - → Soln: $x = A_1 e^{-\gamma_1 t} + A_2 e^{-\gamma_2 t}$



- $\gamma^2 = \omega_0^2$: Critical damping
  - → equal roots
  - → not really oscillatory, decays asymptotically
  - → Soln: $x = A_1 e^{-\gamma t} + A_2 e^{-\gamma t} t$

- $\gamma^2 < \omega_0^2$: underdamping
  - → Complex roots
  - → oscillatory, exponentially decreasing amplitude
  - → Soln: $x = ae^{i\omega_d t - \gamma t} + be^{-i\omega_d t - \gamma t}$

$= Ae^{-\gamma t}\cos(\omega_d t - \theta)$

$a = \frac{A}{2}e^{-i\theta}$; $b = \frac{A}{2}e^{i\theta}$; ω_d natural frequency ; $T_d = \frac{2\pi}{\omega_d}$

$\omega_d = \sqrt{\omega_0^2 - \gamma^2} \approx \omega_0 - \frac{\gamma^2}{2\omega_0}$ (small damping)

4.3) Inertial Forces - 91

- O_1: $\vec{F} = m\vec{A}$

- O_2: $\vec{F} = m\vec{a} + m\vec{A_0}$

  or $\vec{F} - m\vec{A_0} = m\vec{a}$

  $\downarrow$

  inertial term: stems only from choice of coord sys

→ Inertial sys: no inertial term

→ In O_2 it seems as though there is an extra force $-m\vec{A_0}$ — an inertial force.

Eg) A block is on a rough table. If the table is accelerated, when will the block slip?

Let O_1 be with the block, O_2 with a point on the table.

In O_2, the block will slip if:

$$|\vec{F} - m\vec{A_0}| > 0$$
$$|\mu \vec{F_N} - m\vec{A_0}| > 0$$
$$|-m\vec{A_0}| > |\mu mg|$$
$$|\vec{A_0}| > \mu g$$

~~In O_1, the block will slip if:~~