Target IIT-JEE 2015

Physics

Gravitation

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Introduction

- Earth attracts all bodies towards its centre. Newton generalized the law by saying that not only the earth but all materials bodies in the universe attract each other with some force. This is known as Newton's Universal Law of Gravitation.

Newton’s Universal Law of Gravitation

- According to Newton's Universal Law of Gravitation, the force of attraction \( F \) between two point masses \( m_1 \) and \( m_2 \) is directly proportional to the product of their masses and inversely proportional to the square of the distance \( r \) between them and is directed along the line joining them.

\[
F \propto \frac{m_1 m_2}{r^2}
\]

Therefore, 
\[
F \propto \frac{1}{r^2}
\]

Combining we get, 
\[
F = \frac{G m_1 m_2}{r^2}
\]

(\text{Newton’s Universal Law of Gravitation})

where \( G = \text{constant of proportionality known as Universal Gravitational Constant.} \)

\( G = 6.67 \times 10^{-11} \text{Nm}^2/\text{kg}^2 \) (Universal Gravitational Constant)

Important Points about Newton's Universal Law of Gravitation

1. Newton's Universal Law of Gravitation states that 
\[
F = \frac{G m_1 m_2}{r^2}
\]

This expression is valid for point masses (particles) only.

1. Gravitational force \( F \) acts along the line joining the two particles and is attractive in nature.

2. We can treat large bodies as point masses, if the distance \( r \) between them is very large compared to their sizes.

For example, we can treat Earth and Sun as particles because the distance between them is quite large compared to their radii.

3. A uniform sphere or a spherical shell attracts a particle that is outside it as if all the mass were concentrated at its centre.

Thus, a uniform spherical body or a uniform hollow spherical body act as a point mass at its centre when another particle is outside.

4. A uniform shell of matter exerts no net gravitational force on a particle located inside it.

Gravitational force on a particle from an extended body

- We have to find gravitational force acting on a particle of mass \( m_1 \) from an extended body of mass \( m \). Here we use the concept of superposition.

- We divide the body into infinitesimally small segments, such that each segments behaves as a particle.

- Let us consider an infinitesimally small segment of mass \( dm \) at a distance \( r \) from the particle \( m_1 \).

- Hence, net gravitational force acting on particle from extended body

\[
F = \int dF = \int G m_1 \frac{dm}{r^2}
\]
**Acceleration due to Gravity**

- Earth attracts every body with an acceleration which is known as acceleration due to gravity. It is denoted by \( g \). Its value depends on many factors and does not remain constant. We use \( g = 9.8 \) m/s\(^2\) near the Earth’s surface to solve most of the problems.
- **NOTE:** Acceleration due to gravity \( g \) (small \( g \)) is not same as Universal gravitational constant \( G \) (capital \( G \)). Value of \( G \) is constant anywhere in the Universe but the value of \( g \) changes from place to place.

**Acceleration due to Gravity Near the Earth’s surface**

- Let us consider Earth to be a **uniform sphere** of mass \( M \).
- As we have assumed earth to be a uniform sphere, it will attract a body outside its surface as though all the mass were concentrated at its centre.
- At a particular instant when the distance of particle from Earth centre is \( r \), gravitational force is given by

\[
F = \frac{GmM}{r^2}
\]

- Using Newton’s Second Law of Motion \((F = ma = mg)\) and Newton's Law of Gravitation \( F = \frac{GmM}{r^2} \), we get

\[
F = mg = \frac{GmM}{r^2}
\]

\[
g = \frac{GM}{r^2}
\]

- Note that this acceleration is independent of the mass of the body itself.
- If the body is near the Earth’s surface, we can replace \( r \) with radius \( R \) of the Earth. Therefore, acceleration due to gravity near the Earth’s surface is

\[
g = \frac{GM}{R^2}
\]

(acceleration due to gravity near Earth’s surface)

- The value of \( g \) is typically taken to be \( 9.8 \) m/s\(^2\) near the Earth’s surface.

**Important Points to note about acceleration due to Gravity**

- The expression \( g = \frac{GM}{R^2} \) for acceleration due to gravity is deduced assuming Earth to be a uniform sphere and neglecting effect of Earth’s rotation.
- We are going to study the variation in acceleration due to gravity because of following effects:
  1. Altitude (height) above the earth’s surface
  2. Depth below the Earth’s surface
  3. Rotation of Earth (Variation with latitude).

**Variation of acceleration due to gravity with Altitude above Earth’s surface**

- Let us consider a body of mass \( m \) at a height \( h \) above the surface of the Earth. Let us consider Earth to be a uniform sphere of mass \( M \) and radius \( R \). Clearly, the body is at a distance \((R + h)\) from the center of the Earth. Therefore, gravitational force is

\[
F = \frac{GmM}{(R + h)^2}
\]

- If \( g_h \) is the value of acceleration due to gravity at that point, then from Newton’s 2\(^{nd} \) law,

\[
F = ma = mg_h
\]

- Hence, \( F = \frac{GmM}{(R + h)^2} = mg_h \)

\[
g_h = \frac{GM}{(R + h)^2} \quad \ldots(i)
\]

- We want to write this expression in terms of acceleration due to gravity near Earth’s surface, i.e., in terms of \( g = \frac{GM}{R^2} \). Therefore, we multiply & divide denominator of expression (i) by \( R^2 \). Thus, we get,

\[
g_h = \frac{GM}{R^2} \left(1 + \frac{h}{R} \right)^2 = \frac{GM}{R^2} \left(1 + \frac{h}{R} \right)^2
\]

- As, \( g = \frac{GM}{R^2} = \) acceleration due to gravity at Earth’s surface. Therefore,

\[
g_h = g \left(1 + \frac{h}{R} \right)^2
\]

(acceleration due to gravity at a height \( h \) from surface)

- In general, we are interested in those bodies which are not very far away from the surface. Therefore, for the case, when \( h \) is much smaller than \( R \), i.e., \( h \ll R \), we have from Binomial Expansion,

\[
\left(1 + \frac{h}{R} \right)^2 = 1 - \frac{2h}{R}
\]

Hence,

\[
g_h = g \left(1 - \frac{2h}{R} \right) \quad \text{(for} \ h \ll R \text{)}
\]

(acceleration due to gravity at a height \( h \) from surface)

- Thus, the value of gravitational acceleration decreases linearly as one moves away from the surface of the Earth.
Funda Session: The main idea here is that the body will be attracted by the mass of the Earth which is enclosed in a sphere of radius \((R - h)\). There will be no net attraction from the mass of the Earth which lies outside the sphere of radius \((R - h)\).

Reason: A uniform shell of matter exerts no net gravitational force on a particle located inside it and earth can be considered as a nest of such shells. Hence shells outside this body produces no net attraction.

Variation of gravitational acceleration due to depth below Earth’s surface

- Consider a body of mass \(m\) taken to a depth \(h\) inside the Earth’s surface. Let us consider Earth to be a uniform sphere of mass \(M\) and radius \(R\).
- Let us find the mass of this portion of the sphere which lies inside radius \(R - h\).
- Mass per unit volume of the earth \(= \frac{3M}{4\pi R^3}\)
- Hence, mass of the Earth inside the radius \((R - h)\), \(M' = \frac{M}{4\pi R^3} \times \frac{4}{3} \pi (R - h)^3\)

\[M' = \frac{M}{R^3} (R - h)^3\]  \(\ldots (i)\)

- Thus, gravitational force acting on the body at a depth \(h\) below the Earth’s surface is

\[F = \frac{GM'm}{(R - h)^2} = \frac{GMm(R - h)}{R^2}\]

\(\text{(Using (i))}\)

- Let us denote acceleration due to gravity at this point by \(g_h\). Therefore, from Newton’s 2\textsuperscript{nd} Law we have,

\[F = ma \Leftrightarrow F = m \cdot g_h\]

\(\text{(iii)}\)

- Using (ii) & (iii) we get:

\[mg_h = \frac{GMm(R - h)}{R^3} \Rightarrow g_h = \frac{GM}{R^2} \left( \frac{R - h}{R} \right)\]

\[\Rightarrow g_h = g \left(1 - \frac{h}{R}\right)\]

\(\text{(acceleration due to gravity at a depth} h \text{ from surface)}\)

- Thus, the value of gravitational acceleration decreases if one moves towards the center of the Earth, e.g., in mines.
Variation of \( g \) with Rotation and Latitude

- Let us consider Earth is rotating with an angular speed \( \omega \). Let us consider a particle of mass \( m \) at rest wrt the Earth at latitude \( \phi \).
- Then the pseudo force acting on the particle is \( mr \omega^2 \) in outward direction. The true acceleration ‘\( g \)’ is acting towards the centre O of the earth. Thus, the effective acceleration ‘\( g \)’ is the resultant of \( g \) and \( r \omega^2 \) or,

\[
g' = \sqrt{g^2 + (2 \omega^2)^2 + 2g(\omega^2)\cos(180 - \phi)}
\]

- Here, the term \( r^2 \omega^4 \) comes out to be too small as \( \omega = \frac{2\pi}{24 \times 3600} \text{ rad/s} \) is small. Hence, this term can be ignored. Also \( r = R \cos \phi \). Therefore, Eq. (i) can be written as

\[
g' = \left(g^2 - 2R \omega^2 \cos^2 \phi \right)^{\frac{1}{2}}
\]

\[
g' = g \left(1 - \frac{2R \omega^2 \cos^2 \phi}{g}\right)
\]

\[
\approx g \left(1 - \frac{R \omega^2 \cos^2 \phi}{g}\right)
\]

Thus, \( g' = g - \omega R \cos^2 \phi \)

- Following conclusions can be drawn from the above discussion:
  (i) The effective value of \( g \) is not truly vertical.
  (ii) The effect of centrifugal force due to rotation of earth is to reduce the effective value of \( g \).
  (iii) At equators \( \phi = 0^0 \)
      Therefore \( g' = g - R \omega^2 \)
      And at poles \( \phi = 90^0 \)
      Therefore, \( g' = g \)
      Thus, at equation \( g' \) is minimum while at poles \( g' \) is maximum.

Gravitational Potential Energy

- **Gravitational Potential Energy (U):** The work done by external force (or negative of work done by gravitational force) in bringing point masses from infinity to their respective positions without acceleration is called the gravitational potential energy of the system.

- It is represented usually by \( U \) and is given mathematically as

\[
U = -W = -\frac{Gm_1m_2}{r}
\]

- The gravitational potential energy at infinity is assumed to be zero.
- Gravitational Potential Energy is a scalar quantity.
- The gravitational potential energy is a property of system of two or more particles rather than of either particle alone.

Derivation of Gravitational Potential Energy

- Consider a system of two masses \( m_1 \) and \( m_2 \). Suppose, the mass \( m_1 \) is fixed at a point \( A \) and the mass \( m_2 \) is taken from a point \( B \) to infinity (\( \infty \)) along the line \( AB \).

\[
\begin{align*}
\int_{r}^{\infty} \frac{Gm_1m_2}{r^2} dr &= -Gm_1m_2 \left( \frac{1}{r} - \frac{1}{\infty} \right) \\
&= \frac{Gm_1m_2}{r}
\end{align*}
\]

- The total work done as the mass \( m_2 \) moves from \( B \) to \( C \) is

\[
W = \int_{r}^{\infty} \frac{Gm_1m_2}{r^2} dr = -Gm_1m_2 \left( \frac{1}{r} - \frac{1}{\infty} \right)
\]

Thus, the potential energy is, therefore,

\[
U = -W = -\frac{Gm_1m_2}{r} \quad \ldots(\text{i})
\]

- We choose the potential energy of the two-mass system to be zero when they have infinite separation (that means when they are widely separated). This means \( U (\infty) = 0 \).

Gravitational Potential Energy of three mass system

\[
U = -\left(\frac{Gm_1m_2}{r_1} + \frac{Gm_2m_3}{r_2} + \frac{Gm_3m_1}{r_3}\right)
\]

(Derivation is discussed in class)
Gravitational Potential Energy of four mass system

\[
U = \left( \frac{Gm_1m_2}{r_{12}} + \frac{Gm_1m_3}{r_{13}} + \frac{Gm_1m_4}{r_{14}} + \frac{Gm_2m_3}{r_{23}} + \frac{Gm_2m_4}{r_{24}} + \frac{Gm_3m_4}{r_{34}} \right)
\]

Kepler’s Laws

Kepler formulated the laws of planetary motion. The three laws are:

1. **All planets move in elliptical orbits with the sun at one of the focus.**
   
   This law is also known as The Law of Orbits.

2. **The radius vector from the sun to the planet sweeps equal areas in equal time.**
   
   This law is also known as The Law of Areas.
   
   - We can say it in a different way as, the rate \( \frac{dA}{dt} \) at which a planet sweeps out an area \( A \) is constant. \( dA/dt \) is also known as areal velocity meaning area swept out per unit time by the radius vector from the Sun to the planet. Thus, we can state this law as: The areal velocity of planet is constant.

3. **The square of the time period of a planet is proportional to the cube of the semi-major axis of the ellipse.**
   
   This law is also known as The Law of Periods.
   
   - Let the time period of the planet be \( T \). Also assume the length of the semi-major axis be \( a \). Then according to Kepler’s third law we have:
     \[
     T^2 \propto a^3
     \]

   For two planets we have,
   \[
   \left( \frac{T_1}{T_2} \right)^2 = \left( \frac{a_1}{a_2} \right)^3
   \]
   
   - Time period is also given by formula:
     \[
     T^2 = \frac{4\pi^2}{GM} a^3
     \]

   where \( M \) = mass of the Sun which is constant.

Orbital Velocity and time period of a satellite

a) **Orbital velocity:**

- *Orbital velocity of a satellite is the velocity required to put the satellite into its orbit around the earth.*

- Suppose that a satellite of mass \( m \) has to be put into circular orbit around the earth at a height \( x \) above its surface. Consider that earth is a sphere of mass \( M \) and radius \( R \). Then, the radius of the orbit of the satellite will be \( R + x \). Suppose that \( v \) is the required orbital velocity for the satellite.

- The gravitational force of attraction between the satellite and the earth will provide the necessary centripetal force to the satellite to move around the earth in the circular orbit i.e.

\[
\frac{GMm}{(R+x)^2} = \frac{mv^2}{R+x}
\]

\[
\Rightarrow v = \sqrt{\frac{GM}{R+x}} \quad \ldots \text{(i)}
\]

- The acceleration due to gravity, \( g \), on the surface of the earth is given by

\[
g = \frac{GM}{R^2}
\]

Putting the value of \( GM \) in equation (i), we have

\[
v = \sqrt{\frac{gR}{R+x}} \quad \ldots \text{(ii)}
\]

- The equations (i) and (ii) are used to find the orbital velocity for a satellite orbiting at a height \( x \) above the surface of earth.

- It may be pointed out that the orbit of the satellite may not be circular in shape. However, the orbits are assumed to be circular ones, only for the sake of simplicity.

- **Special case:** When the satellite is orbiting very close to the surface of the earth: In such a case, \( x \approx 0 \). From equation (i) and (ii), we have

\[
v = \sqrt{\frac{gR}{R}} = \sqrt{gR} \quad \ldots \text{(iii)}
\]

By substituting \( g = 9.8 \text{ ms}^{-2} \) and \( R = 6.4 \times 10^6 \text{m} \) in equation (iii), it comes out that a satellite requires a velocity of about \( 7.92 \text{ km s}^{-1} \) to revolve in a orbit just near the surface of earth.

b) **Time period of satellite:**

- The time period of a satellite is the time taken by it to go once around the earth. Therefore,

\[
T = \frac{\text{circumference of the orbit}}{\text{orbital velocity}}
\]

\[
T = \frac{2\pi (R+x)}{v} \quad \ldots \text{(iv)}
\]

- Substituting the value of \( v \) given by equation (i) in equation (iv), we have

\[
T = \frac{2\pi (R+x)}{\sqrt{\frac{GM}{R+x}}}
\]
Gravitation

\[ T = 2\pi \sqrt{\frac{(R + x)^3}{GM}} \ldots (v) \]

- Setting \( GM = gR^2 \) in equation (v), we have
\[ T = 2\pi \frac{(R + x)^3}{R \sqrt{g}} \ldots (vi) \]

Equations (v), (vi) give the time period of a satellite revolving at a height \( x \) above the surface of the earth.

- **Special case:** When the satellite revolves very close to the surface of the earth: In such a case, \( x \approx 0 \). Setting \( x = 0 \), equations (v), (vi) gives
\[ \frac{3}{2} \frac{R^2}{g} \pi = \pi \ldots (vii) \]

By substituting \( g = 9.8 \text{ m/s}^2 \) and \( R = 6.4 \times 10^6 \text{ m} \) in the equation (vii), it comes out that the time period of a satellite revolving around the earth just close to its surface is about 84.6 minutes.

**Quick exercise**

Q. Find the total mechanical energy of an orbiting satellite.

Ans: \[ E = \frac{-GMm}{2(R + x)} \]

**Explanation:**

When a satellite revolves around a planet in its orbit, it possesses both potential energy of the satellite in the orbit at a height \( x \) above the surface of earth is given by
\[ U = \frac{GMm}{R + x} \ldots (i) \]

Since the satellite revolves in its orbit around the planet under the effect of its gravitational pull, we have
\[ \frac{mv^2}{R + x} = \frac{GMm}{(R + x)^2} \]

or \[ mv^2 = \frac{GMm}{R + x} \]

Therefore, the kinetic energy of the satellite in its orbit,
\[ K = \frac{1}{2} mv^2 = \frac{GMm}{2(R + x)} \ldots (ii) \]

Hence, total energy of a satellite in its orbit,
\[ ME = U + K = \frac{-GMm}{R + x} + \frac{GMm}{2(R + x)} \]
\[ ME = -\frac{GMm}{2(R + x)} \ldots (iii) \]

It follows that energy of an orbiting satellite is negative. For this reason, the planet and the orbiting satellite are said to from a bound system.

**Escape Velocity**

- Escape velocity is the initial speed required to go from an initial point in a gravitational potential field to infinity with a residual velocity of zero, with all speeds and velocities measured with respect to the field.

- We can also define escape velocity as the minimum velocity an object must have in order to escape the gravitational field of the earth, that is, escape the earth without ever falling back.

- From the surface of the Earth, escape velocity (ignoring air friction) is about 11.2 km/s relative to Earth. Given that initial speed, an object needs no additional force applied to completely escape Earth's gravity.

- The simplest way of deriving the formula for escape velocity is to use conservation of energy.

- Suppose a particle of mass \( m \) is at a distance \( r \) from the center of mass of the planet, whose mass is \( M \).

- Its initial speed is equal to its escape velocity, \( v_e \).

- At its final state, it will be an infinite distance away from the planet, and its speed will be negligibly small and assumed to be 0.

- Kinetic energy \( K \) and gravitational potential energy \( U \) are the only types of energy that we will deal with, so by the conservation of mechanical energy for the planet-mass system, we have
\[ K_1 + U_1 = K_2 + U_2 \]

\[ \frac{1}{2} mv_e^2 - \frac{GMm}{r} = 0 + 0 \]

\[ (K_2 = 0 \text{ because final velocity is zero, and } U_2 = 0 \text{ because its final distance is infinity}) \]

\[ \Rightarrow v_e = \sqrt{\frac{2GM}{r}} \]

**Gravitational field Intensity**

- Suppose we are interested to find gravitational field intensity due to a mass \( M \) at a point \( P \). This mass \( M \) is known as **source mass** \( M \).

- We need a **small mass** \( m_o \) at point \( P \). This second kind of mass is very small compared to that of source mass \( M \) and is known as **test mass** \( m_o \).

  \[ \overrightarrow{E} \]

  \[ \text{Source mass} \]

  \[ \text{Test mass} \]

- In the next step, we find gravitational force \( \overrightarrow{F} \) acting on test mass \( m_o \) because of source charge \( M \). Gravitational field \( \overrightarrow{E} \) because of source mass \( M \) at point \( P \) is nothing but the gravitational force \( \overrightarrow{F} \) per unit small positive test mass \( m_o \) placed at that point \( P \). Thus,
\[ \overrightarrow{E} = \lim_{m_o \to 0} \frac{\overrightarrow{F}}{m_o} \quad \text{(Gravitational field intensity)} \]

- Clearly, the direction of \( \overrightarrow{E} \) is along \( \overrightarrow{F} \).
• Definition of Gravitational Field Intensity

The gravitational field intensity or simply electric field \( E \) due to a source mass \( M \) at a point is defined as the gravitational force \( F \) per unit small mass charge \( m_o \) acting on \( m_o \) due to \( M \) placed at that point.

\[
E = \lim_{m_o \to 0} \frac{F}{m_o}
\]

(Gravitational field intensity)

• Important points about electric field

1. In the LHS of the expression \( E = \lim_{m_o \to 0} \frac{F}{m_o} \), \( E \) is the gravitational field due to source mass \( M \) but in the RHS, test mass \( m_o \) appears. Be careful of this.
2. \( F \) is the gravitational force acting on the test mass \( m_o \) because of source mass \( M \).
3. Gravitational field intensity is a vector quantity.
4. The direction of \( E \) is along \( F \).
5. SI unit of gravitational field: N/kg = newton per kg

Gravitational Field due to a Point Mass

• We wish to find out the gravitational field intensity \( E \) due to a point mass \( M \) at a point \( P \) which is \( r \) distance from it. For this, we have to place another small test mass \( m_o \) at point \( P \).

\[ F = \frac{GMm_o}{r^2} \]

Therefore, magnitude of Gravitational field at that point is

\[ E = \frac{F}{m_o} \]

\[ \Rightarrow \frac{GM}{r^2} \]

(Gravitational field due to a point mass \( M \) at a distance \( r \))

• The direction of \( E \) is along \( F \).

Force on a point mass placed in a Gravitational Field

• Suppose a particle of mass \( m \) is placed in a gravitational field at a point where intensity of gravitational field is \( E \). Then particle experiences a force \( \vec{F} \) in the direction of \( E \), which is given by

\[ \vec{F} = m \vec{E} \]
Gravitation Potential

The work done in bringing a unit mass from infinity to a point in the gravitational field is called the gravitational potential at that point.

\[ V = \frac{W_{cm}}{m_0} = -\frac{W}{m_0} = \frac{U}{m_0} \]

(i) Potential due to a point Mass

Suppose a point mass \(M\) is situated at a point \(O\). We want to find the gravitational potential due to this mass at a point \(P\) a distance \(r\) from \(O\). For this let us find work done in taking the unit mass from \(P\) to infinity. This will be,

\[ W = \int Fdr = \int \frac{GM}{r^2} dr = \frac{GM}{r} \]

Hence, the work done in bringing units from infinity to \(P\) will be \(-\frac{GM}{r}\). Thus, the gravitational potential at \(P\) will be,

\[ V = -\frac{GM}{r} \]

(ii) Potential due to a Uniform Solid Sphere

Potential at an External point

The gravitational potential due to a uniform sphere at an external point is same as that due to a single particle of same mass placed at its centre. Thus,

\[ V(r) = -\frac{GM}{r}, \quad r \geq R \]

At the surface, \(r = R\) and \(V = -\frac{GM}{R}\)

Potential at Internal Point

At some internal point, potential at a distance \(r\) from the centre is given by,

\[ V(r) = -\frac{GM}{R^2} \left( \frac{3}{2} R^2 - \frac{1}{2} r^2 \right), \quad r \leq R \]

At \(r = R\), \(V = -\frac{GM}{R}\)

while at \(r = 0\), \(V = -1.5\frac{GM}{R}\)

i.e., at the centre of the sphere the potential is 1.5 times the potential at surface.

(iii) Potential due to a Uniform Thin Spherical Shell

Potential at an External point

To calculate the potential at an external point, a uniform spherical shell may be treated as a point mass of same magnitude at its centre. Thus, potential at a distance \(r\) is given by,

\[ V(r) = -\frac{GM}{r}, \quad r \geq R \]

\[ V = -\frac{GM}{R}, \quad \text{at } r = R, \]

Potential at an Internal point

The potential due to a uniform spherical shell is constant throughout at any point inside the shell and this is equal to \(-\frac{GM}{R}\).

Relation between gravitation field and potential

Gravitational potential is a field function. It depends on the position of the point where potential is desired. Gravitation potential are related by the following relation.

\[ \vec{E} = \left[ \frac{\partial V}{\partial x} i + \frac{\partial V}{\partial y} j + \frac{\partial V}{\partial z} k \right] \]

Here, \(\frac{\partial V}{\partial x}\) = partial derivative of potential function \(V\) w.r.t. \(x\), i.e., differentiate \(V\) w.r.t. \(x\) assuming \(y\) and \(z\) to be constant

Eq.(i) can be written in following different forms.

i. \(E = \frac{dv}{dx}\), if gravitational field is along x-direction only

ii. \(dV = -E.d\vec{r}\),

Here,

\[ d\vec{r} = dx\hat{i} + dy\hat{j} + dz\hat{k} \]

and \(\vec{E} = E_x\hat{i} + E_y\hat{j} + E_z\hat{k}\)
# Physics Classes by Pranjal Sir

*(Admission Notice for XI & XII - 2014-15)*

## Batches for Std XIIth

**Batch 1** (Board + JEE Main + Advanced): (Rs. 16000)

**Batch 2** (Board + JEE Main):  (Rs. 13000)

**Batch 3** (Board): (Rs. 10000)

**Batch 4** (Doubt Clearing batch): Rs. 8000

## About P. K. Bharti Sir (Pranjal Sir)

- **B. Tech., IIT Kharagpur (2009 Batch)**
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### Physics Class Schedule for Std XIIth (Session 2014-15) by Pranjal Sir

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<td>Vectors, FBD, Work, Energy, Rotation, SHM</td>
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<td>Electric Field</td>
<td>10th &amp; 12th Apr</td>
<td>10th &amp; 12th Apr</td>
<td>10th &amp; 12th Apr</td>
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<td></td>
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<td>Gauss’s Law</td>
<td>13th &amp; 15th Apr</td>
<td>13th &amp; 15th Apr</td>
<td>13th &amp; 15th Apr</td>
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<td>Competition Level</td>
<td>NA</td>
<td>17th &amp; 19th Apr</td>
<td>17th &amp; 19th Apr</td>
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<td>2.</td>
<td>Electrostatic Potential and Capacitance</td>
<td>Electric Potential</td>
<td>20th &amp; 22nd Apr</td>
<td>20th &amp; 22nd Apr</td>
<td>20th &amp; 22nd Apr</td>
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<td>Capacitors</td>
<td>24th &amp; 26th Apr</td>
<td>24th &amp; 26th Apr</td>
<td>24th &amp; 26th Apr</td>
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<td>Competition Level</td>
<td>NA</td>
<td>27th &amp; 29th Apr</td>
<td>27th &amp; 29th Apr, 1st, 3rd &amp; 4th May</td>
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<tr>
<td><strong>PART TEST 1</strong></td>
<td>Unit 1 &amp; 2</td>
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<td>4th May</td>
<td>NA</td>
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<td>NA</td>
<td>11th May</td>
<td>11th May</td>
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<td>3.</td>
<td>Current Electricity</td>
<td>Basic Concepts, Drift speed, Ohm’s Law, Cells, Kirchhoff’s Laws, Wheatstone bridge, Ammeter, Voltmeter, Meter Bridge, Potentiometer etc.</td>
<td>6th, 8th, 10th, 13th May</td>
<td>6th, 8th, 10th, 13th May</td>
<td>6th, 8th, 10th, 13th May</td>
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<td>Competition Level</td>
<td>NA</td>
<td>15th &amp; 16th May</td>
<td>15th, 16th, 17th, 18th &amp; 19th May</td>
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<td><strong>PART TEST 2</strong></td>
<td>Unit 3</td>
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<td>18th May</td>
<td>NA</td>
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<td>NA</td>
<td>20th May</td>
<td>20th May</td>
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<td><strong>SUMMER BREAK</strong></td>
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<td>21st May 2013 to 30th May 2013</td>
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<td>4.</td>
<td>Moving charges and Magnetism</td>
<td>Force on a charged particle (Lorentz force), Force on a current carrying wire, Cyclotron, Torque on a current carrying loop in magnetic field, magnetic moment</td>
<td>31st May, 1st &amp; 3rd Jun</td>
<td>31st May, 1st &amp; 3rd Jun</td>
<td>31st May, 1st &amp; 3rd Jun</td>
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<td>Biot Savart Law, Magnetic field due to a circular wire, Ampere circuital law, Solenoid, Toroid</td>
<td>5th, 7th &amp; 8th Jun</td>
<td>5th, 7th &amp; 8th Jun</td>
<td>5th, 7th &amp; 8th Jun</td>
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<td>Competition Level</td>
<td>NA</td>
<td>10th &amp; 12th Jun</td>
<td>10th, 12th, 14th &amp; 15th Jun</td>
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<td><strong>PART TEST 3</strong></td>
<td>Unit 4</td>
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<td>15th Jun</td>
<td>NA</td>
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<td>5.</td>
<td>Magnetism and Matter</td>
<td>Faraday’s Laws, Lenz’s Laws, A.C. Generator, Motional Emf, Induced Emf, Eddy Currents, Self Induction, Mutual Induction</td>
<td>17&lt;sup&gt;th&lt;/sup&gt;, 19&lt;sup&gt;th&lt;/sup&gt; &amp; 21&lt;sup&gt;st&lt;/sup&gt; Jun</td>
<td>17&lt;sup&gt;th&lt;/sup&gt;, 19&lt;sup&gt;th&lt;/sup&gt; &amp; 21&lt;sup&gt;st&lt;/sup&gt; Jun</td>
<td>Not in JEE Advanced Syllabus</td>
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<td>6.</td>
<td>Electromagnetic Induction</td>
<td>24&lt;sup&gt;th&lt;/sup&gt;, 26&lt;sup&gt;th&lt;/sup&gt; &amp; 28&lt;sup&gt;th&lt;/sup&gt; Jun</td>
<td>24&lt;sup&gt;th&lt;/sup&gt;, 26&lt;sup&gt;th&lt;/sup&gt; &amp; 28&lt;sup&gt;th&lt;/sup&gt; Jun</td>
<td>24&lt;sup&gt;th&lt;/sup&gt;, 26&lt;sup&gt;th&lt;/sup&gt; &amp; 28&lt;sup&gt;th&lt;/sup&gt; Jun</td>
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<td>Competition Level</td>
<td>NA</td>
<td>29&lt;sup&gt;th&lt;/sup&gt; Jun &amp; 1&lt;sup&gt;st&lt;/sup&gt; Jul</td>
<td>29&lt;sup&gt;th&lt;/sup&gt; Jun, 1&lt;sup&gt;st&lt;/sup&gt;, 3&lt;sup&gt;rd&lt;/sup&gt; &amp; 5&lt;sup&gt;th&lt;/sup&gt; Jul</td>
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<td>PART TEST 4</td>
<td>Unit 5 &amp; 6</td>
<td>6&lt;sup&gt;th&lt;/sup&gt; Jul</td>
<td>NA</td>
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<td>Unit 5 &amp; 6</td>
<td>NA</td>
<td>13&lt;sup&gt;th&lt;/sup&gt; Jul</td>
<td>13&lt;sup&gt;th&lt;/sup&gt; Jul</td>
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<td>7.</td>
<td>Alternating current</td>
<td>AC, AC circuit, Phasor, transformer, resonance,</td>
<td>8&lt;sup&gt;th&lt;/sup&gt;, 10&lt;sup&gt;th&lt;/sup&gt; &amp; 12&lt;sup&gt;th&lt;/sup&gt; Jul</td>
<td>8&lt;sup&gt;th&lt;/sup&gt;, 10&lt;sup&gt;th&lt;/sup&gt; &amp; 12&lt;sup&gt;th&lt;/sup&gt; Jul</td>
<td>8&lt;sup&gt;th&lt;/sup&gt;, 10&lt;sup&gt;th&lt;/sup&gt; &amp; 12&lt;sup&gt;th&lt;/sup&gt; Jul</td>
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<td>19&lt;sup&gt;th&lt;/sup&gt; &amp; 20&lt;sup&gt;th&lt;/sup&gt; Jul</td>
<td>19&lt;sup&gt;th&lt;/sup&gt; &amp; 20&lt;sup&gt;th&lt;/sup&gt; Jul</td>
<td>Not in JEE Advanced Syllabus</td>
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<td>8.</td>
<td>Electromagnetic Waves</td>
<td>Upto unit 8</td>
<td>31&lt;sup&gt;st&lt;/sup&gt; Jul &amp; 2&lt;sup&gt;nd&lt;/sup&gt; Aug</td>
<td>31&lt;sup&gt;st&lt;/sup&gt; Jul &amp; 2&lt;sup&gt;nd&lt;/sup&gt; Aug</td>
<td>31&lt;sup&gt;st&lt;/sup&gt; Jul &amp; 2&lt;sup&gt;nd&lt;/sup&gt; Aug</td>
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<td>Grand Test 1</td>
<td>Upto Unit 8</td>
<td>3&lt;sup&gt;rd&lt;/sup&gt; Aug</td>
<td>3&lt;sup&gt;rd&lt;/sup&gt; Aug</td>
<td>3&lt;sup&gt;rd&lt;/sup&gt; Aug</td>
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<td>Ray Optics</td>
<td>Reflection</td>
<td>5&lt;sup&gt;th&lt;/sup&gt; &amp; 7&lt;sup&gt;th&lt;/sup&gt; Aug</td>
<td>5&lt;sup&gt;th&lt;/sup&gt; &amp; 7&lt;sup&gt;th&lt;/sup&gt; Aug</td>
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<td>Refraction</td>
<td>9&lt;sup&gt;th&lt;/sup&gt; &amp; 12&lt;sup&gt;th&lt;/sup&gt; Aug</td>
<td>9&lt;sup&gt;th&lt;/sup&gt; &amp; 12&lt;sup&gt;th&lt;/sup&gt; Aug</td>
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<td>Prism</td>
<td>14&lt;sup&gt;th&lt;/sup&gt; Aug</td>
<td>14&lt;sup&gt;th&lt;/sup&gt; Aug</td>
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<td>Optical Instruments</td>
<td>16&lt;sup&gt;th&lt;/sup&gt; Aug</td>
<td>16&lt;sup&gt;th&lt;/sup&gt; Aug</td>
<td>Not in JEE Adv Syllabus</td>
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<td>19&lt;sup&gt;th&lt;/sup&gt; &amp; 21&lt;sup&gt;st&lt;/sup&gt; Aug</td>
<td>19&lt;sup&gt;th&lt;/sup&gt;, 21&lt;sup&gt;st&lt;/sup&gt;, 23&lt;sup&gt;rd&lt;/sup&gt;, 24&lt;sup&gt;th&lt;/sup&gt; Aug</td>
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<td>Wave Optics</td>
<td>Huygens Principle</td>
<td>26&lt;sup&gt;th&lt;/sup&gt; Aug</td>
<td>26&lt;sup&gt;th&lt;/sup&gt; Aug</td>
<td>26&lt;sup&gt;th&lt;/sup&gt; Aug</td>
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<td>Interference</td>
<td>28&lt;sup&gt;th&lt;/sup&gt; &amp; 30&lt;sup&gt;th&lt;/sup&gt; Aug</td>
<td>28&lt;sup&gt;th&lt;/sup&gt; &amp; 30&lt;sup&gt;th&lt;/sup&gt; Aug</td>
<td>28&lt;sup&gt;th&lt;/sup&gt; &amp; 30&lt;sup&gt;th&lt;/sup&gt; Aug</td>
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<td>31&lt;sup&gt;st&lt;/sup&gt; Aug</td>
<td>31&lt;sup&gt;st&lt;/sup&gt; Aug</td>
<td>31&lt;sup&gt;st&lt;/sup&gt; Aug</td>
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<td>2&lt;sup&gt;nd&lt;/sup&gt; Sep</td>
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<td>2&lt;sup&gt;nd&lt;/sup&gt; Sep</td>
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<td>4&lt;sup&gt;th&lt;/sup&gt; &amp; 6&lt;sup&gt;th&lt;/sup&gt; Sep</td>
<td>4&lt;sup&gt;th&lt;/sup&gt;, 6&lt;sup&gt;th&lt;/sup&gt;, 7&lt;sup&gt;th&lt;/sup&gt;, 9&lt;sup&gt;th&lt;/sup&gt;, 11&lt;sup&gt;th&lt;/sup&gt; Sep</td>
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<td>PART TEST 6</td>
<td>Unit 9 &amp; 10</td>
<td>14&lt;sup&gt;th&lt;/sup&gt; Sep</td>
<td>14&lt;sup&gt;th&lt;/sup&gt; Sep</td>
<td>14&lt;sup&gt;th&lt;/sup&gt; Sep</td>
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<td>DUSSEHRA &amp; d-ul-Zuha Holidays: 29&lt;sup&gt;th&lt;/sup&gt; Sep to 8&lt;sup&gt;th&lt;/sup&gt; Oct</td>
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<td>11.</td>
<td>Dual Nature of Radiation and Matter</td>
<td>Photoelectric effect etc</td>
<td>9&lt;sup&gt;th&lt;/sup&gt; &amp; 11&lt;sup&gt;th&lt;/sup&gt; Oct</td>
<td>9&lt;sup&gt;th&lt;/sup&gt; &amp; 11&lt;sup&gt;th&lt;/sup&gt; Oct</td>
<td>9&lt;sup&gt;th&lt;/sup&gt; &amp; 11&lt;sup&gt;th&lt;/sup&gt; Oct</td>
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<td>12.</td>
<td>Atoms</td>
<td>Upto Unit 10</td>
<td>12&lt;sup&gt;th&lt;/sup&gt; Oct</td>
<td>12&lt;sup&gt;th&lt;/sup&gt; Oct</td>
<td>12&lt;sup&gt;th&lt;/sup&gt; Oct</td>
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<td>13.</td>
<td>Nuclei</td>
<td>14&lt;sup&gt;th&lt;/sup&gt; &amp; 16&lt;sup&gt;th&lt;/sup&gt; Oct</td>
<td>14&lt;sup&gt;th&lt;/sup&gt; &amp; 16&lt;sup&gt;th&lt;/sup&gt; Oct</td>
<td>14&lt;sup&gt;th&lt;/sup&gt; &amp; 16&lt;sup&gt;th&lt;/sup&gt; Oct</td>
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<td>X-Rays</td>
<td>18&lt;sup&gt;th&lt;/sup&gt; &amp; 19&lt;sup&gt;th&lt;/sup&gt; Oct</td>
<td>18&lt;sup&gt;th&lt;/sup&gt; &amp; 19&lt;sup&gt;th&lt;/sup&gt; Oct</td>
<td>18&lt;sup&gt;th&lt;/sup&gt; &amp; 19&lt;sup&gt;th&lt;/sup&gt; Oct</td>
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<td>PART TEST 7</td>
<td>Unit 11, 12 &amp; 13</td>
<td>26&lt;sup&gt;th&lt;/sup&gt; Oct</td>
<td>NA</td>
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<td>14.</td>
<td>Semiconductors</td>
<td>Basic Concepts and Diodes, transistors, logic gates</td>
<td>26&lt;sup&gt;th&lt;/sup&gt;, 28&lt;sup&gt;th&lt;/sup&gt;, 30&lt;sup&gt;th&lt;/sup&gt; Oct &amp; 1&lt;sup&gt;st&lt;/sup&gt; Nov</td>
<td>26&lt;sup&gt;th&lt;/sup&gt;, 28&lt;sup&gt;th&lt;/sup&gt;, 30&lt;sup&gt;th&lt;/sup&gt; Oct &amp; 1&lt;sup&gt;st&lt;/sup&gt; Nov</td>
<td>Not in JEE Adv Syllabus</td>
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<td>15.</td>
<td>Communication System</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt; &amp; 4&lt;sup&gt;th&lt;/sup&gt; Nov</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt; &amp; 4&lt;sup&gt;th&lt;/sup&gt; Nov</td>
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<td>PART TEST 8</td>
<td>Unit 14 &amp; 15</td>
<td>9&lt;sup&gt;th&lt;/sup&gt; Nov</td>
<td>9&lt;sup&gt;th&lt;/sup&gt; Nov</td>
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<td>Unit 11, 12 &amp; 13</td>
<td>Competition Level</td>
<td>NA</td>
<td>8&lt;sup&gt;th&lt;/sup&gt;, 9&lt;sup&gt;th&lt;/sup&gt; &amp; 11&lt;sup&gt;th&lt;/sup&gt; Nov</td>
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<td>Unit 11, 12, 13, X-Rays</td>
<td>NA</td>
<td>16&lt;sup&gt;th&lt;/sup&gt; Nov</td>
<td>16&lt;sup&gt;th&lt;/sup&gt; Nov</td>
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<td>Revision Round 2 (Board Level)</td>
<td>Mind Maps &amp; Back up classes for late registered students</td>
<td>18&lt;sup&gt;th&lt;/sup&gt; Nov to Board Exams</td>
<td>18&lt;sup&gt;th&lt;/sup&gt; Nov to Board Exams</td>
<td>18&lt;sup&gt;th&lt;/sup&gt; Nov to Board Exams</td>
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<td>Revision Round 3 (XIth portion for JEE)</td>
<td>18&lt;sup&gt;th&lt;/sup&gt; Nov to JEE</td>
<td>18&lt;sup&gt;th&lt;/sup&gt; Nov to JEE</td>
<td>18&lt;sup&gt;th&lt;/sup&gt; Nov to JEE</td>
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<td>30 Full Test Series</td>
<td>Complete Syllabus</td>
<td>Date will be published after Oct 2014</td>
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