PHY 101
PART II

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INTRODUCTION

The Universe means totallity of Space. The physical Universe includes; the Sun and the rest of Solar system, the Stars in their galaxies, the natural Satellite (moons), the artificial Satellites, meteors and meteorite, space dust and Space Vacuum.

The Universe is represented mathematically as a rectangle. And any object of study in the Universe can be Conveniently represented in the rectangle, while the rest of Space in the rectangle refers to the environment of the object.

Space - Time (t, x) Refrence frames.

The four fundamental forces in nature are:
(i) Electromagnetic (EM) forces
(ii) Gravitational "
(iii) Strong Nuclear "
(iv) Weak " "

A refrence frame is a Mathematical Coordinate system which contain an Observer and the object he focus at with respect to an Origin.

Examples of coordinate Systems are Eucleadean or Cartesian Coordinate System, Spherical coordinate System, and Cylindrical Coordinate System.

Assignment: State one perculiar use to which each of the coordinate System mentioned above can be applied.

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The two categories of refrence frames are: (i) Inertia refrence frame
(ii) non-Inertia refrence frame
An Inertia refrence frame is that which is Completely motionless with respect to the rotation of the earth or the Universe at large.

A System is the Object of focus or Study, and the rest of the Universe is its environment

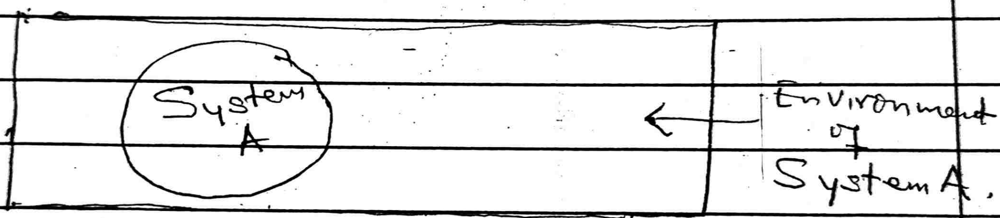

FIG 1: Showing a System illustration

The System could be a particle, object or ~~forces~~ field of a force. There is always a form of interaction between a system and its environment - Often involving motion of one type or the other.

Each interaction registers an event, and every event occurs at a time (t) and a location x, (x, y) or (x, y, z), considering 1 Dimension, 2D or 3D cases.

Consider two Observers of the Same phenomenon or events A and B, which are in different refrence frame X and Y

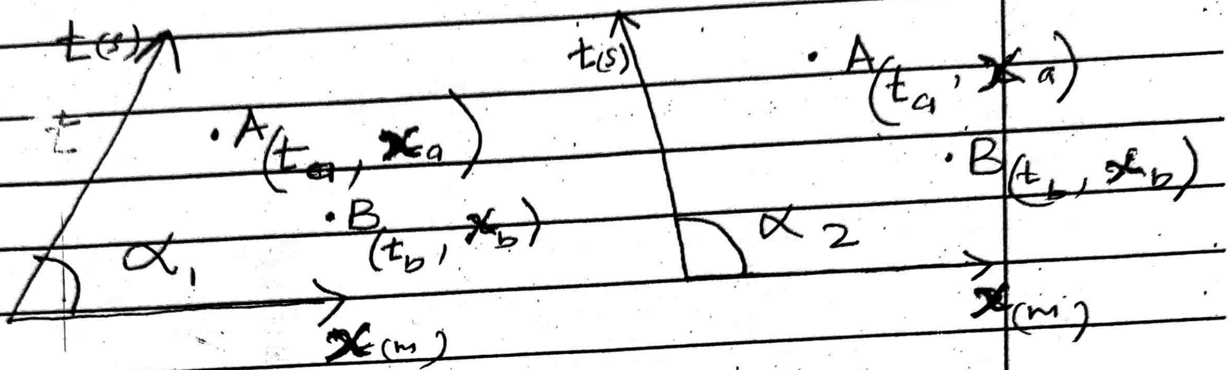

FIG 2: Showing Event A and B by Two Different Refrence frame α_1 and α_2 [where $\alpha \neq \pi/2$]

Here the events $A_{(t_a, x_a)}$ and $B(t_a, x_b)$ have temporal (time) difference of occurrence $(t_b - t_a)$ generally defined as T, and Spacial Separation $(x_b - x_a)$ denoted by L or Length. Points $A_{(t_a, x_a)}$ and $B_{(t_b, x_b)}$ may be Space-time Coordinate of the Same particle or object Q of mass M. Recall M, L and T are fundamental dimension of physical quantity.

For application of physics laws to analyse their observations and compare their results, the two observers must use decribed physics terms, for example stating precisely whether their motion is linear, Circular or Spiral.

If One of the observer moves at 'Constant Velocity' w.r.t the other it is refered to

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Galilean Transformation.

The Galilean transformation is the simplest case of observation of same event by two observers in that one observer moves at constant velocity w.r.t the other.

Domains of Physics

The following are the four domains of physics:

I. Non quantum and non relativistic Domain called Newtonian Mechanics

II. Non quantum and Relativistic Domain

III. Quantum and non relativistic Domain

IV. Quantum and relativistic Domain

Mechanics is the study of the relationship between net force and resulting motion or simply why motion occur. Newtonian mechanics refers to study of ~~object~~ interaction between objects which are large relative to atomic size and have speed of interaction low relative to speed of light.

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Force and Motion

When objects interact they exert forces on one another. The net force experience by each object in their intereaction ~~the~~ determine how each of the Object move.

Motion is said to occur when an object changes its position and/ or orientation w.r.t time.

Representation of position along x, y and z axes is defined by

$$r = ai + bj + ck$$

where i, j and k are orthogonal unit vectors along the axes x, y and z. S.I unit of distance (d) between any two point is metre (m) and S.I. unit of time is seconds. Though you should give your answers to the required units, otherwise give them in S.I. Units.

Exercise What is the differece b/w r and

M

Solution r is a position vector while d is just a distance between any two positions.

LECTURE III

Types and Planes of Motion

Types of Motion

i. Rectilinear motion
ii. Rotational or Circular Motion
iii. Projectile "
iv Helical "
* v SHM
v. Orbital
* vi. Spin

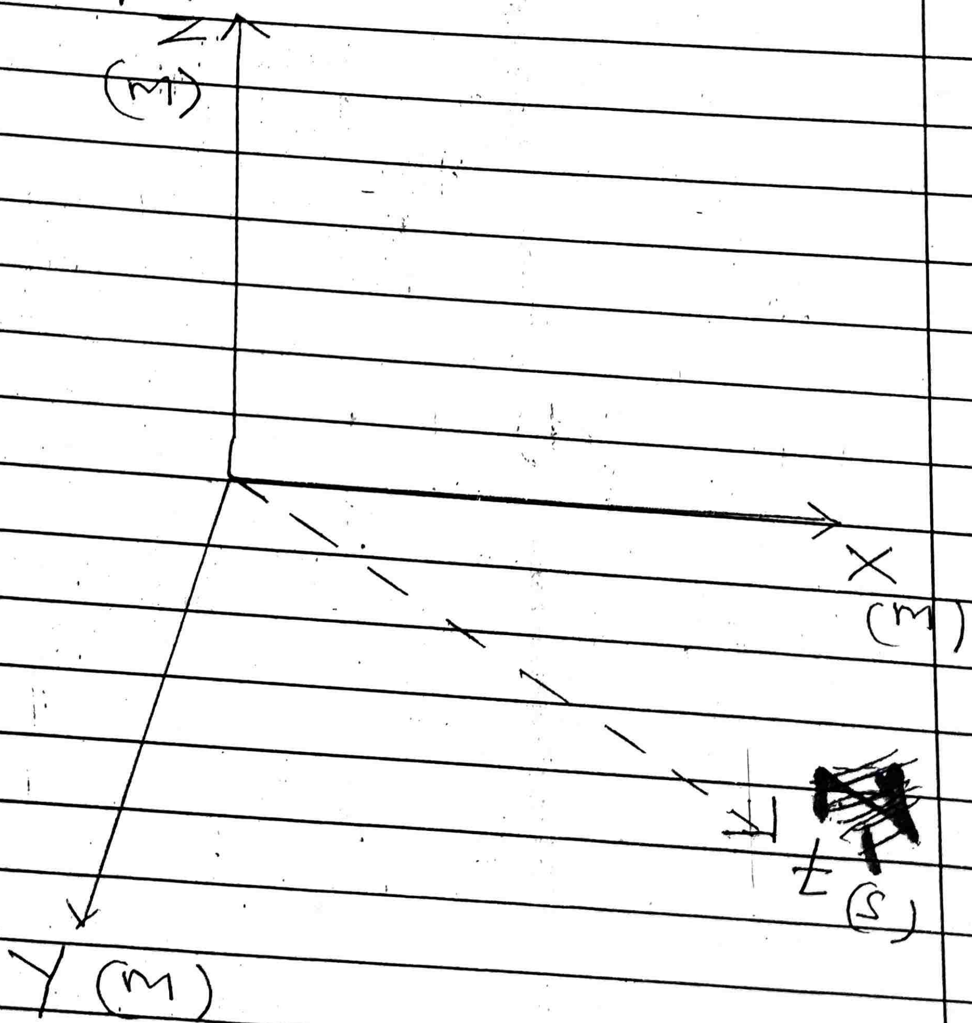

FIG 3

Rectilinear motion may be defined as the motion of an object which change its position along one defined axis (X, Y or Z) w.r.t time.

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Rotational motion is the motion of an object which changes both its (1) position along one or more defined axes (X, Y, Z), planes (XY, XZ, YZ), or space (XYZ) and its (2) Orientation w.r.t time

Projectile motion is the motion an object describe when it changes its position w.r.t time in one or more planes (XY, XZ, YZ) simultaneously.

Helical motion is the motion an object describe when it accelerates or decelerates uniformly in a rotational motion.

Simple Harmonic Motion [SHM] is the motion an object describe when its acceleration is directly proportional to its ~~distance~~ displacement from a defined fixed point, such that it is always directed towards that point

i.e $\bar{a} \propto -r \Rightarrow \bar{a} = -kr$

where $r = x$ or y or z axis.

The negative sign indicate that although the acceleration is larger at larger displacement, it is always in the opposite direction to the displacement

SHM is one example of class or group called Oscillatory motions in which the moving object moves about a fixed point, or position.

Spin is the motion of an object which changes only its Orientation ~~with~~ w.r.t time.

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Orbital motion is the motion an object describe when it performs oscillatory motion about the position of another object (Primary). Though the object constantly move about the position of the primary object, the primary object's position may ~~simultaneously~~ also be changing.

Gravitational Motion

Forces generally may be classified into two, namely 'contact forces' and 'field forces'.

Gravitational force is the cause of gravitational motion, it is a field force, i.e. it acts in a field.

A field is defined as the region in which a force can be experienced

Gravitational force F_{kj} exerted on a body of mass m_j by the Earth at distance r_{jk} from the centre of the earth is given by

$$F_{kj} = \frac{G M_k m_j}{(r_{jk})^2} \hat{r}_{jk} \quad ---(1)$$

Where M_k = mass of the earth

F_{kj} is the net force exerted by M_k on m_j. Hence motion occur as m_j is attracted or moved towards the earth ie M_k, ~~over~~ along $\hat{r}_{jk}$ (Unit Vector).

Recall r may be written

$$\bar{r} = a\hat{i} + b\hat{j} + c\hat{k}$$

$$\text{and } \hat{r} = \hat{i} + \hat{j} + \hat{k}$$

where a, b and c are constants and $\hat{i}, \hat{j}$, and $\hat{k}$ are Unit Vectors along X, Y and Z axis respectively.

Escape Velocity

If the mass m_j is escaping from the Earth mass M_k and radius r_E, then

Potential energy gained by the body = Kinetic energy lost by the body

Work done measure the energy change. The work done (dw) by gravity when the body m_j moved a short distance dz upwardly:

$$dw = -F\,dz$$

$$= -\frac{G M_k m_j\, dz}{z^2}$$

Total work done while body escapes $= \int_r^{\infty} -\frac{G M_k m_j}{z^2}\, dz$

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$$= -GM_k m_j \int_r^\infty \frac{1}{z^2}\,dz$$

$$= -GM_k m_j \left[-\frac{1}{z}\right]_r^\infty$$

$$= GM_k m_j \left[\frac{1}{z}\right]_r^\infty$$

$$= GM_k m_j \left(0 - \frac{1}{r}\right)$$

$$= -\frac{GM_k m_j}{r}$$

At escape

$$\frac{1}{2} m_j V^2 = \frac{GM_k m_j}{r}$$

$$V = \sqrt{\frac{2GM}{r}}$$

but $g = \frac{GM}{r^2}$

therefore $V = \sqrt{2gr}$

$$= \left[2 \times 9.8\,m/s^2 \times 6.4 \times 10^6\right]^{1/2}$$

$$= 11.2\ Km/s$$

Kepler's Law of planetary motion states:

1. Each planet moves in an ellipse which has the Sun at one focus

2. The line joining the sun to the moving planet(s) sweep out equal areas in equal times

3. The Squares of the times of revolution of the planet i.e (periodic time T) about the Sun are proportional to the cubes of the mean distance r from it, i.e

- r cannot be shown on the illustrative diagram, been a mean distance

$$\frac{r^3}{T^2} = \text{Constant}$$

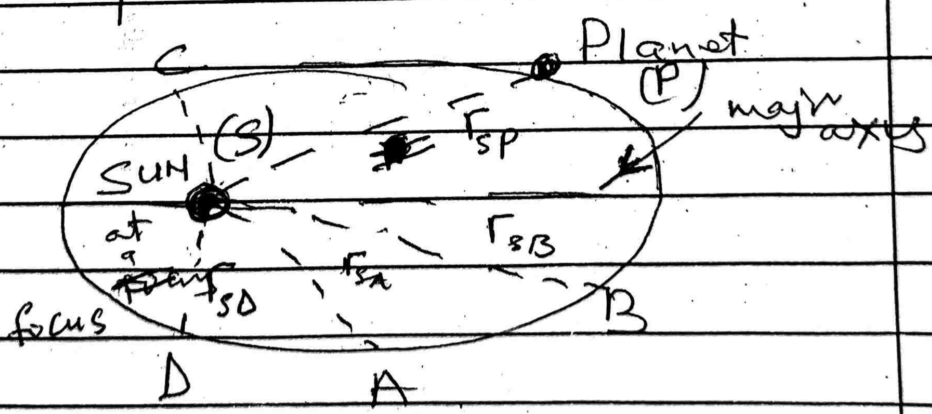

FIG 4

baby ~~monkey~~ monkey carried by Daddy shoulder on their shoulder

Examples on Force Application

1. A child whirls a stone tied to a string round a horizontal circle of radius 0.8m at a speed 5.01m/s. Calculate the stone's centripetal acceleration.

Soln

$$\bar{a} = -\frac{V^2}{r}\hat{r} \quad (1)$$

$$= -\frac{(5m/s)^2}{0.8m}\hat{r}$$

— negative sign indicate direction of $\bar{a}$ is opposite to $\hat{r}$, where $\hat{r}$ is a unit vector along the radial path ($\hat{r}$), and it implies the force is directed inwardly (n) hence called centripetal. When is the force centrifugal?

2. A truck pusher applied 720N over a distance of 20m before the engine of the truck start. Obtain the work done by the man [14, 400 J]. Assuming the truck moved at a constant velocity when being pushed, calculate its velocity if the mass of the truck is 5.1×10^3 kg [$\sqrt{5.76}$ m/s along the direction of the force]

57 m/s

Hint: Work done by truck pusher = K.E. gained by the truck $= \frac{1}{2}mv^2$

$V = $ ~~14400~~

$= \sqrt{\frac{2 \times 14400}{m}}$

3. (a) State the two forms of mechanical energy

(b) What is energy? List often forms.

(c) What is energy conservation principle

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4. Generally in rotational ~~mo~~motions the method ~~employ~~ commonly used in calculating magnitudes and direections of force, velocity and acceleration is calculus.

If a spherical ballon move in a three dimentional space such that the relationship between the radial path (r)m of its motion is related to it times (t)s of travel in the motion, by

$$\bar{r} = 3t^2 - t + 4$$

(i) estimate the acceleration of the ballon assuming uniform motion.

Given $\bar{r} = 3t^2 - t + 4$

Velocity $(V) = \frac{dr}{dt} = 6t - 1$, along $\hat{r}$

and the constant acceleration (a) of the uniform motion is given by

$$\bar{a} = \frac{d^2 r}{dt^2} = 6 \text{ m/s}^2$$

(ii) If the ballon experience a constant net force (F_N) in the motion and it mass (m) is 0.01kg, evaluate the net force causing the motion.

Generally $F = ma$

$$F_N = 0.01\text{kg} \times 6\text{m/s}^2$$
$$= 0.06\text{N}$$

(iii) What will happen to the ballon if the set of forces acting on it suddenly

$5t^2 - t + 2$

$\frac{dr}{dt} = 10t - 1$

$\frac{d^2r}{dt} = a = 10 \text{ m/s}^2$

$F_N = ma$
$= 0.01\text{kg} \times 10$
$= 0.1\text{N}$

Changed and the F_H Vanished (i.e F_H = 0 Newton in (a) Still air

$\rightarrow F_H = mg = 0.01kg \times 9.8m/s = 0.098N$

(b) breeze of uniform Velocity $0.3m/s \hat{Z}$
(c) breeze of " " $-0.3m/s \hat{Z}$

(iv) What will be the acceleration in the breeze $0.3m/s \hat{Z}$, 2 seconds after been in the still air

Generally $V = u + at$

$\therefore 0.3m/s = 0 + a(2s)$

$a = 0.15 m/s^2$

(V) Considering acceleration $(\bar{a})$

(a) What is meant by Uniform motion $[\bar{a} = \text{constant}]$

(b) What is meant by Non Uniform motion $[\bar{a} \text{ Varies}]$
- for example in circular motion.

(c) What is meant by a Constant Velocity motion $[\bar{a} = 0 m/s^2]$
note not 0.

(M)

LECTURE V

I. MOMENTS OF INERTIA.

Consider the stone being whirled by a child in the example above. The static refrence frame may be represented thus

To find for rotation:
1. Moment of inertia ($\bar{I}$)
2. C.G.
3. Total Angular Momentum (L)
4. Torque (T)

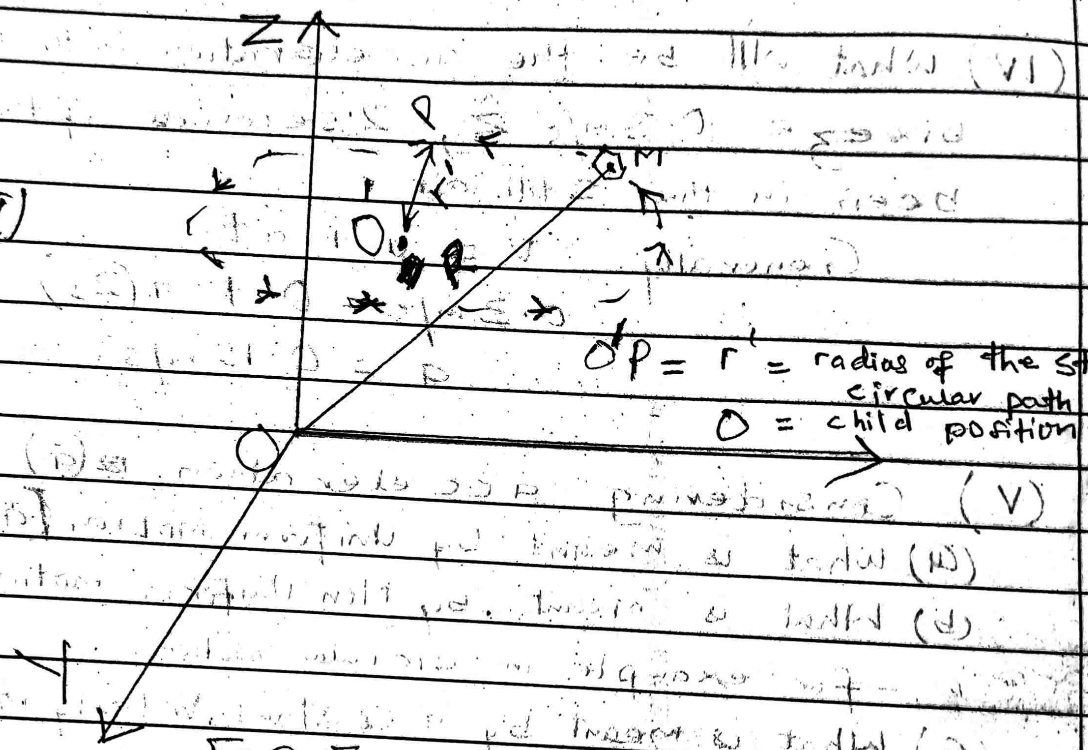

FIG 5

If the stone mass (M) is made up of several thousands of sand particles of different masses $m, m_2, m_3, m_4, m_5 \ldots \ldots m_i$ and in their ~~Compa~~ compact state each of the sand particles are at distance $r_1, r_2, r_3, r_4, r_5 \ldots r_i$ from the Origin O, then the stone's compact location or mass point vector $\bar{r}$ is given by

$$\bar{r} = \frac{\sum_{i=1}^{n} m_i r_i^2}{M} = \frac{I}{M} \quad - (2)$$

note $\bar{I} \neq I$

Where $\bar{I} = \sum_{i=1}^{n} m_i r_i^2$ — (3)

= Moment of Inertia for rotation about specified axis.

Applications of Moment of Inertia

The centre of mass of the object (stone) is called Centre of gravity (C G). The centre of gravity of an object defined its stable location position called balance position or balance point, outside which the object will be unstable under the force of gravity.

In some circumstances a rotating body's total angular momentum (L) about a defined origin is given by the moment of inertia ($\bar{I}$) and angular velocity ($\bar{\omega}$) thus:

Total angular Momentum ($\bar{L}$) = $\bar{I}\,\bar{\omega}$ — (4)

Also the net turning force called torque (T) is given by the moment of inertia and angular acceleration (α) of the object, thus:

Torque ($\bar{T}$) = $I\alpha$ — (5)

The relationship between SHM and moment of inertia can be briefly analysed using the popular pendulum bob.

In simple pendulum motion the bob is said to perform SHM if the pendulum its displacement (θ) is small such that

$\sin\theta \doteq \theta$ (6)

The forces basically acting on the

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bob is given by figure 6.

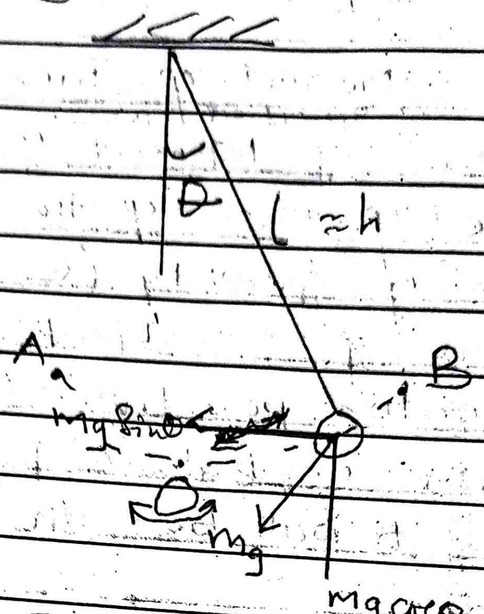

FIG 6: Simple Pendulum Mechanics:

If the relationship between the bob's changing position w.r.t time (t) is given by

$$\bar{r}(t) = A \sin \omega t$$

then

$$\bar{V}(t) = \frac{d\bar{r}(t)}{dt} = \frac{d}{dt}[A \sin \omega t]$$

$$= A \frac{d}{dt}[\sin \omega t]$$

$$= A\omega \cos \omega t, \text{ along } \hat{r}.$$

and

$$\bar{a}(t) = \bar{g} = \frac{d\bar{V}(t)}{dt} = \frac{d}{dt}[A\omega \cos \omega t]$$

$$= -A\omega^2 \sin \omega t$$

[skipping steps]:

$$\Rightarrow \quad \omega = \sqrt{\frac{mgh}{I}}$$

$r(t) = 0.9 \sin 2t$

$\bar{V}(t) = 0.9 \times 2 \cos 2t$

$= 1.8 \cos 2t$

$\bar{a} = -0.9 \times 4 \sin 2t$

$t = 2$

$\bar{a} = -2.72144589$

$= -2.72 \, m/s^2$

$t = 3$

$= -0.376$

Now by definition

$$\omega = 2\pi f$$

and Period $(T) = \frac{1}{f} = \frac{\omega}{2\pi}$

$$= 2\pi\sqrt{\frac{I}{mgh}}$$

$$\therefore T^2 = \frac{4\pi^2 I}{mgh}$$

$$\Rightarrow \underset{\text{(moment of inertia about O)}}{I} = \frac{T^2 mgh}{2\pi} \quad (7)$$

which estimates the turning effect of ~~the~~ force ~~of~~ of gravity (F_g) on the bob about O.

II. ROTATION OF RIGID BODIES

Another quantity angular momentum (I) is also related to the net turning force (T) w.r.t time (t) of the rotational Motion of the object, thus:

$$T = \frac{dI}{dt} \quad (8)$$

$$\text{and} \quad T = \bar{r} \times \bar{F} \quad (9)$$

Given $\bar{r} = a_1\hat{i} + a_2\hat{j} + a_3\hat{k}$ and $\bar{F} = b_1\hat{i} + b_2\hat{j} + b_3\hat{k}$

then $T = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ a_1 & a_2 & a_3 \\ b_1 & b_2 & b \end{vmatrix} \quad -(10)$

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For example if
$\bar{r} = 3i + 4j + 8k$
and $F = 6i + 2j - 4k$

then, $\bar{T} = \bar{r} \times \bar{F} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ 3 & 4 & 8 \\ 6 & 2 & -4 \end{vmatrix}$

$= i \begin{vmatrix} 4 & 8 \\ 2 & -4 \end{vmatrix} - j \begin{vmatrix} 3 & 8 \\ 6 & -4 \end{vmatrix} + k \begin{vmatrix} 3 & 4 \\ 6 & 2 \end{vmatrix}$

$\Rightarrow \bar{T} = -32i + 60j - 18k$

Generally the rotating objects angular momentum L about the origin O of an inertia refrece frame is constant (If not net force act on It) i.e $T = 0$, if the net force acting on It is always directed towards that origin as in SHM.

Consider orbital planetary motion in which the primary object exerts an attractive central force F on the Secondary object (mass m), in an inertia frame whose origin O is at the force centre.

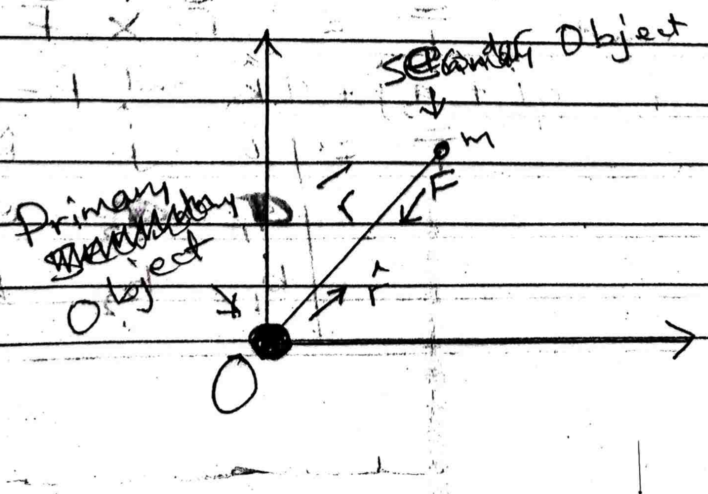

FIG 7.

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i.e $\bar{F} = -|\bar{F}|\,\hat{r}$

Where $|\bar{F}| = \sqrt{b_1^2 + b_2^2 + b_3^2}$; if as in the previous example ① $\bar{F} = 6\hat{i} + 2\hat{j} - 4\hat{k}$

$|\bar{F}| = \sqrt{6^2 + 2^2 + (-4)^2}$

$= 7.5N.$ $\quad$ 7.48 N

= magnitude of the attractive central force.

② $F = 5\hat{i} + \hat{j} - 4\hat{k}$

$|F| = 6.71N$