Philosophy of Physics

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Course Information

- Name of the Instructor: S. Uma Sankar
- Email Address: uma@phy.iitb.ac.in
- Lecture Timings: Monday 11:35 AM and Thursday 9:30 AM
- Tutorial Timing: Tuesday 11:35 AM (No Tutorial this week)
- Moodle: The lecture slides will be uploaded on the URL **moodle.iitb.ac.in** every friday. Tutorial sheets for the next week will also be loaded on the same URL. You can log into this URL by using your official IITB user-id and password.

Course Grading

- Quiz-I: 15 mark Quiz for 1 hour, to be held in the second half of August
- Mid-Semester Exam: 30 mark Exam for 2 hours, to be held during September 6-13.
- Quiz-II: 15 mark Quiz for 1 hour, to be held in the first half of October.
- End-Semester Exam: 40 mark Exam for 3 hours, to be held during November 7-18.

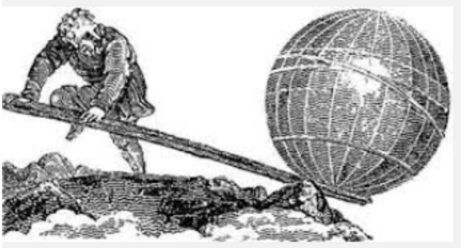
Topics to be Covered

1. Motivation for Quantum Theory.
2. Experimental proof for the quantum hypothesis: Compton Effect.
3. De-Broglie hypothesis and matter waves
4. Phase velocity and Group velocity, Heisenberg's uncertainty Principle
5. Schroedinger's equation and its solution for free particles
6. Particle in an infinite potential well
7. Particle in a finite potential well
8. Scattering off a potential of infinite extent
9. Scattering off a potential of finite extent
10. Tunnelling
11. Simple Harmonic Oscillator
12. Particle in an infinite potential well in two and in three dimensions, counting the degeneracy
13. Quantum Statistics: Maxwell-Boltzmann, Bose-Einstein and Fermi-Dirac distributions
14. Some applications of M-B, B-E and F-D distributions.
15. Introduction to Solid State Physics.

Early Studies of Motion

Since the earliest times, people are interested in how to move things. To move heavy objects in a controlled manner is of great practical importance.

To this end, a number of practical devices, such as pullies and levers, were developed. Their properties were studied and their operation was understood in quantitative (or mathematical) terms.



Archimedes is supposed to have boasted, Give me a firm spot on which to stand, and I shall move the earth.

Beginning of Dynamics

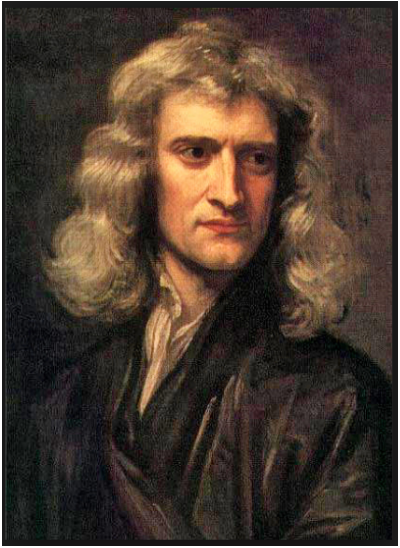
The general problem of describing the motion of an arbitrary body was not considered. There were only some philosophical hypotheses of Aristotle regarding the inertia of bodies.

The systematic study of motion was started by Galileo. He demanded that any hypothesis must be tested by detailed experimental observations.

Galileo himself conducted a number of measurements of bodies sliding down inclines and derived the kinematic relations obeyed by masses moving with uniform acceleration. He also enunciated what we call Newton's First Law.

Christiaan Huygens deduced that a body moving in a circular orbit experiences an acceleration directed to the center of the circle. In fact, he anticipated Newton's Second Law by showing that such a particle experiences a centripetal force $= mv^2/r$.

Enter Newton



Enter Newton

Newton made Dynamics a full fledged discipline of study by his three famous works:

- Calculus
- The Three laws of Motion
- Law of Universal Gravitation

Question: How did Newton derive his laws of motion?

Enter Newton

Answer: Newton **did not** derive his laws of motion.

Newton's laws are mathematical expressions summarizing a large number of measurements made on various different kinds of motion.

They are called **empirical** laws. Their justification is based only on measurements. They can not be mathematically derived.

The laws of pulleys and levers, when they were originally written down, were also empirical laws. But, once we accept Newton's laws of motion as the more basic laws, the laws of pulleys and levers can be derived.

Newton's law of gravitation, however, can be derived from Kepler's laws of planetary motion.

Derivation of Newton's Law of Gravitation

Kepler's laws imply that the orbit of a planet is in a plane. So we use plane polar coordinates r and θ to describe this motion.
Note: $x = r\cos\theta$ and $y = r\sin\theta$.

In plane polar coordinates, the position vector and the acceleration are

$$\vec{r} = r\hat{r}(\theta) \ \text{ and } \ \vec{a} = (\ddot{r} - r\dot{\theta}^2)\hat{r} + (r\ddot{\theta} + 2\dot{r}\dot{\theta})\hat{\theta},$$

where $\hat{\theta}$ is the unit vector perpendicular to $\hat{r}$ in the anti-clockwise direction.

The mathematical expressions for Kepler's first two laws are

$$r = \frac{r_0}{1 - \epsilon\cos\theta} \ \text{ and } \ r^2\dot{\theta} = C,$$

where r_0, ϵ and C are constants.

From the second law, we can show that the coefficient of $\hat{\theta}$ in the expression for $\vec{a}$ is zero (that is acceleration is purely radial).

From the first law, we can show that the radial acceleration is $\propto 1/r^2$.
From the force law, we can derive Kepler's third law.

Influence of Newton

When Newton's discoveries were publicised, various people came up with explanations of diverse natural phenomena, especially tides, based on Newton's laws of motion and of gravitation.

Scientists of succeeding generations developed Newton's ideas further and made dynamics a very active field of research.

Some notable examples are:

- Calculus of variations developed by *Johann Bernoulli*
- Rigid Body dynamics by *Euler*
- Generalized dynamics by *Lagrange*
- Dynamics as an evolution in time by *Hamilton*

Mechanical View of Nature

After Newton, the following point of view became a principle of physics. The preferred method of the mathematical description of any physical problem is through a differential equation.

For example, Newton's second law is

$$m\frac{d^2x}{dt^2} = F(x, v).$$

If we know the full details of the force $F(x, v)$ acting on an object, then, in principle, we can solve the above differential equation and predict the motion of the object at all times.

Theorem: The most general solution to the nth order Ordinary Differential Equation (ODE) depends n unknown constants. To fix these constants, n intial conditions are needed.

Newton's second law is a second order differential equation. So the most general solution depends on two arbitrary constants. To know the $x(t)$ exactly, we need to know the initial position and the initial velocity.

Mechanical View of Nature

This point of view was applied to a great variety of problems with great success. They include problems of

1. Celestial Mechanics
2. Elasticity
3. Fluid Mechanics
4. Electricity
5. Magnetism
6. Electromagnetic Theory and Optics
7. Thermodynamics and Statistical Mechanics.

Mechanical View of Nature

The philosophy of physics could be summarized by the '*formula*'

$$\text{Speficic Cause} \iff \text{Unique Effect.}$$

In solving physics problems for JEE, you are given the cause (the expression for the force) and are asked to predict what the effect will be.

In the case of gravitation force on planets, Kepler figured out the effect and using Newton's second law, we figured out the cause.

In physics research both the paths are used.

Sometimes, a new and unexpected effect is seen in an experiment. We need to figure out what the cause is based on certain general rules of physics.

Sometimes, an imaginative scientist postulates a new cause, usually based on some symmetry principles, and works out effects of this cause.