# Lecture 0: Introduction to Classical Mechanics

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# About the course

- PH5030 Classical Mechanics – this is a core course for third-year BS/MS students and first-year M.Sc. students.
- If this were a classroom course, we would have had three (50 minute) lectures and one tutorial per week.
- The online course will cover a similar amount of material every week.
- You will receive, on an average, one problem set per week. The tutorial will consist of the following types of questions: some of them will be calculations not done in the lecture, problems that illustrate ideas discussed in the lecture and problems where you teach yourself something in the process of solving them.
- It is extremely important that you attempt to solve the problem sets. It is okay if you are not able to solve it completely. We will discuss them during the tutorial session. Your failed attempt will help you understand the solution better.

# The lecture schedule

- IIT Madras follows a slot system. Slots are labeled A, B, C, and so on. Each slot is allotted a set of hours during the week.
- Every course is fit into a slot. Students can register for only one course in any slot.
- Our course has been allotted the Dslot.
- D Slot: **Mon** 11:00-11:50am, **Tues** 10:00-10:50am, **Wed** 9:00-9:50am and **Thur** 12:00-12:50pm.
- The online mode of lectures can be viewed in two ways: a live lecture or a recorded lecture. The first method is called the synchronous mode and the second method is called asynchronous mode. I will provide the recorded version on the same day as link in google classroom.
- The asynchronous mode is useful for students with limited or poor internet connectivity. It also calls for extreme discipline on the part of students to view the lectures as per the schedule.
- We will use the following interfaces in this course: Moodle, Google Classroom and Google Meet in this course.

# PH5030 Classical Mechanics: Official Syllabus

- Mechanics of a system of particles in vector form. Conservation of linear momentum, energy and angular momentum. Degrees of freedom, generalised coordinates and velocities. Lagrangian, action principle, external action, Euler-Lagrange equations. Constraints. Applications of the Lagrangian formalism. Generalised momenta, Hamiltonian, Hamilton's equations of motion. Legendre transform, relation to Lagrangian formalism. Phase space, Phase trajectories. Applications to systems with one and two degrees of freedom. Central force problem, Kepler problem, bound and scattering motions. Scattering in a central potential, Rutherford formula, scattering cross section.
- Noninertial frames of reference and pseudoforces: centrifugal Coriolis and Euler forces. Elements of rigid-body dynamics. Euler angles. The symmetric top. Small oscillations Normal mode analysis. Normal modes of a harmonic chain.
- Elementary ideas on general dynamical systems: conservative versus dissipative systems. Hamiltonian systems and Liouville's theorem. Canonical transformations, Poisson brackets. Action-angle variables. Non-integrable systems and elements of chaotic motion.
- Special relativity: Internal frames. Principle and postulate of relativity. Lorentz transformations. Length contraction, time dilation and the Doppler effect. Velocity addition formula. Four- vector notation. Energy-momentum four-vector for a particle. Relativistic invariance of physical laws.

# Some books on Classical Mechanics

Main References:

- H. Goldstein, Classical Mechanics, 2nd Edition, Narosa Pub. House (1989).
- I. Percival and D. Richards, Introduction to Dynamics, Cambridge University Press (1987)
- D. Rindler, Special Theory of Relativity, Oxford University Press (1982).

Other books:

- S. T. Thornton and J. B. Marion, Classical Dynamics of Particles and Systems, Brooks Cole, 2003.
- L. N. Hand and J. D. Finch, Analytical Mechanics, Cambridge University Press, Cambridge, 1998.
- L. Landau and E. Lifshitz, Mechanics, Course of Theoretical Physics, Vol 1.

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I do not plan on following any particular book. If I do use a book for a topic, I will let you know during that lecture.

# The evaluation scheme

| | | |
|---|---|---|
| Mini-tests | 20 marks | roughly once a week. |
| 2/3 quizzes | 20 marks | Best 2 considered |
| Take home final | 40 marks. | |

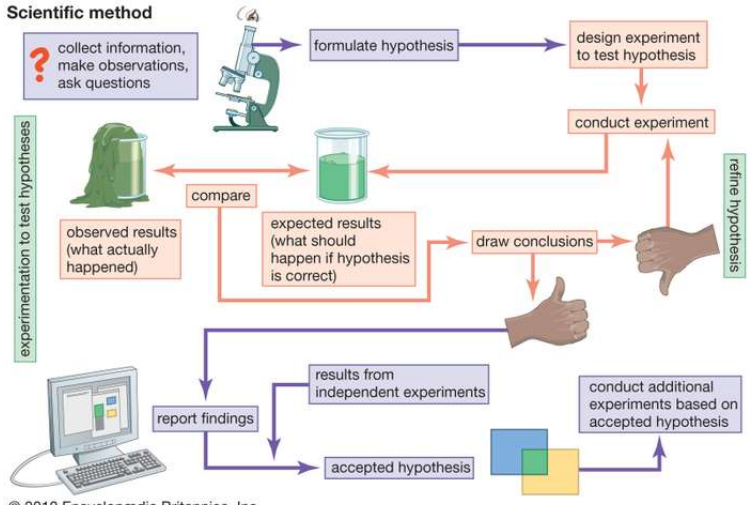
Remarks:

- Mini-tests will be based on the material covered during the past week. It should take 5-10 minutes to take them and it will be online.
- The syllabus for any quiz is ALL material taught until the day before the quiz. This is true for all courses at IITM!
- The duration for a quiz will be one hour.
- The duration for the final will be two hours.
- A margin of time will be allotted for downloading the question paper and uploading of your solution.
- There will be a honour code that you can sign. This is optional and you need not sign it if you don't want to!

# The scientific method

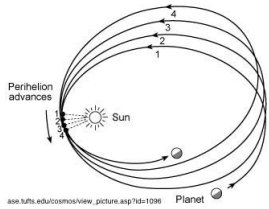
# The scientific method

- The scientific method arose in the development of science over the past few centuries.
- However, the scientific method is applicable to areas other than science. It can be used in social sciences, economics and even literature.
- In particular, modern use in the form of statistical analysis is very common.
- The use of Randomized Custom Trials (RCT) (aka doing experiments) pioneered by Banerjee and Dullo in developmental economics earned them the 2019 Nobel prize in economics along with Kremer.
- As students who will emerge from IITM with a Master's degree, it is imperative that you appreciate and use the scientific method in all aspects of your life, not just your academic career.
- Let us first look at a schematic of how the scientific method works. The linear flow proceeds from empirical observations to hypothesis to testing. This need not always be the case!




Source: https://www.britannica.com/science/scientific-method

# Formulating Hypotheses – an example




- All planets precess, albeit rather slowly – measured in arcseconds per century! This is largely due to the gravitational forces exerted by planets on each other.

| Planet | Planetory effect | Obs. Value | Deficit |
|---|---|---|---|
| Mercury | 532.08 | 575.19 | $43.11 \pm 0.45$ |
| Venus | 13.2 | 21.6 | $8.4 \pm 4.8$ |
| Earth | 1165 | 1170 | $5 \pm 1.2$ |

- This is the empirical/observational data.

# A set of hypotheses

1. There is an extra planet, Vulcan, that is unseen from earth as it is always on the other side of the sun. Its mass and other parameters can account for the extra precession of all planets. [Le Verrier]
2. The gravitational force does not fall off as $1/r^2$ but $1/r^{2-\varepsilon}$ where $\varepsilon$ is very small but can account for the additional precession.
3. The Newtonian law of gravitation has to be modified leading to an effective potential that has an additional $1/r^3$ term. [Einstein]

Can we rule out these hypotheses without further experimentation?

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**Ockham's/Occam's Razor:** In the absence of additional evidence, choose the simplest explanation for an observation.
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# Applications of Occam's Razor

- - Instantaneous action at a distance: You do something on earth and someone feels it immediately in the next galaxy. No
  - You do something on earth and it takes a while for someone to feel it in the next galaxy. Yes
- The location of the planet Saturn can affect you. No
- There is a medicine, Arsenicum Album 30, that can protect you from Covid19. The 30 refers to the dilution – the active ingredient, Arsenic, occurs in 1 part in $100^{30}$. The answer is no because the chance of the active ingredient occuring in the sample of your medication is almost zero.
- Small quantities of Arsenic can provide immunity against Covid19. This cannot be ruled out without further testing.

# Doing experiments to verify hypotheses

- A well motivated hypothesis needs to be substantiated by experiments.
- Before that, it should be consistent with existing results/knowledge to be pursued further.
- The burden of proof is usually left to the person who has proposed the hypothesis!
- The experiments have to be reproducible by others as well.
- Lots of claims of materials that superconduct at room temperature fail the reproducibillity criterion.
- The example of the anomalous precession of Mercury is interesting. Einstein used that as a first test of his theory of general relativity (GR). The theory was also compatible with Newton's universal law of gravitation in a limit. However, it was Eddington and his team's observation of the bending of light by the sun as predicted by GR that lead to a world wide acceptance of the theory. Today, corrections due to GR are routinely incorporated into GPS technology.

# Newton's laws of motion and uniqueness of its solution

1. Newton's first law states that in the absence of external forces, a body will remain in a state of uniform motion. Uniform motion here refers to a constant velocity (not speed).
2. The second law states that this uniform motion can be changed by the action of a force.

The second law is best expressed as a differential equation

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

Mathematics tells us that the solution at times $t > t_0$ is unique if we provide two numbers, at some initial time $t_0$, $\mathbf{x}(t_0)$ and $\dot{\mathbf{x}}(t_0)$. In other words, the results are reproducible.
In this course, we will see that there exists several generalizations of the above statement where this uniqueness is maintained.