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The physics course is divided into four main chapters:

- Dynamics and fluids;
- Thermodynamics;
- Electromagnetism;
- Modern physics;

Lecture 1   26/02

1 - What is **classical physics**?
2 - What is the **scientific method**?
3 - Notion of "**error**"

1 Classical physics is all the physics that comes before Quantum physics, such as:
- Newton's laws;
- Maxwell-Faraday's theory;
- Einstein's general relativity;

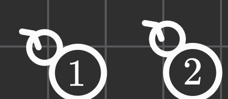
Classical physics is the collection of laws that govern physical phenomena in which quantum uncertainty is not calculated.

If you know everything about a system in the given time and if you know equations that describe the way the system behaves over time, you can theoretically "**predict the future**" and tell what the next state will be.
This means that classical physic is **deterministic:** if a system has deterministic laws it is **reversible** and the starting information is preserved.

Example
Let a system have two states

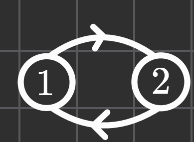
The two possible deterministic laws are

$$\measuredangle(t+1) = \measuredangle(t)$$



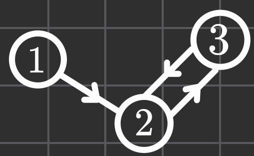
I have no idea of what this symbol is

$$\measuredangle(t+1) = \measuredangle(t-1)$$

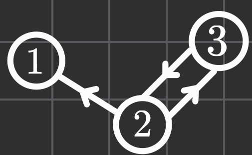


$\measuredangle(t)$ being the starting state

A non-deterministic system is called **ambiguous**: we cannot tell its behaviour with certainty.



This system is ambiguous because if the state is 2 we can't know if it was number 1 or number 3 before.



This system is as well: being in state 2 you can't know if the next state will be number 1 or 3.

All deterministic system states have only one outgoing arrow and only one ingoing arrow.

Exercise

Which of the following laws are classical physics laws?

$$N(t+1) = N(t) - 1$$

$$N(t+1) = N(t) + 2$$

$$N(t+1) = N^2(t)$$

$$N(t+1) = (-1)^{N(t)} \cdot N(t)$$

We can't actually predict with precision the next state: our measurement methods are **not precise enough**.

The phase space of states is in general not discrete, it is infinite and continuous.

Initial conditions can't be known with infinite precision.

Perfect predictability is limited by resolution power.

2 The scientific method

- Empiric experience
- Hypothesis
- Law formulation
- Experimental verification

We observe an event P, which can be explained if H is true. Is H true?
This is a **logical fallacy**: if H, then P is not an exclusive statement, meaning other hypotheses can be found.
Instead:
If H, then C
If not C, then not H
is logically coherent.

In an experiment, every number is associated to a physical quantity: every number is found by measurements, all of which have a relative **error**.
An experiment has reproducibility: physics laws are quantitative relations among physical quantities and these also have reproducibility.

Example of physics ears and range of validity

$$v = s \cdot t$$

This law is limited, it has a range of **validity**.
A more general law can emerge with advancing capabilities.

$$l = l_0(1 + \alpha T)$$ Thermal expansion of a bar

This law is limited by the melting point and the degree of conductivity of the bar.

$$s = v \cdot t$$

This law is limited by the value of v, which has to be constant and much smaller than the speed of light c.
Also time is not absolute: it goes slower when the speed increases.

International system of units (S.I.)

- Length (m) ⟶ Atomic radius $\approx 10^{-11}$ m
- Mass (kg)
- Time (s)
- Electric current (A)
- Thermodynamic temperature (K)
- Amount of substance (mol)
- Luminous intensity (cd)

Fun facts?

A second is defined by the time the light emitted by a Cesium atom to perform 9192631770 oscillations.

Atomic clocks

The age of the Universe is about $5 \cdot 10^{17}$

Background radiation CMB

Dimensional analysis

The symbol representing the measurement unit of a value is [ ]

$[x] = L$ (length)

$[t] = T$ (time)

$$x = \frac{1}{2} a t^2$$

Thanks to the known units we can find the measurement unit of the acceleration.

$$a = \frac{2x}{t^2} \longrightarrow [a] = \frac{L}{T^2}$$

Exercise on units

Planck's time depends on three values:

- $c = 3 \; 10^8 \frac{m}{s}$
- $G = 667 \cdot 10^{-11} \frac{m^3}{s^2 \, kg}$
- $h = 663 \cdot 10^{-3} \; kg \cdot \frac{m^3}{s}$

$$t_p = \sqrt{\frac{hG}{c^5}}$$

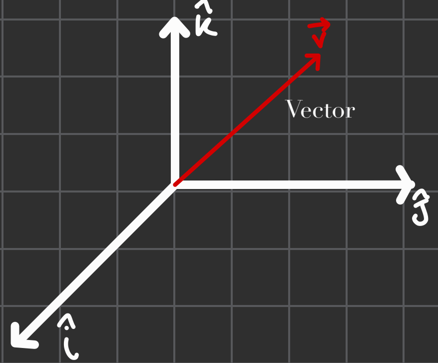
Find the measurement unit of Planck's time (seconds)

Basics of trigonometry and vectors

In order to describe a point in space, we need:

- An arbitrary origin;
- 3 perpendicular axes (Cartesian system);
- 2 implicit assumptions →
  - Time goes by uniformly;
  - Time is the same in every region of the space;

(x, y, z, t) is the definition of a **reference system**.



$$\vec{v} = (v_i, v_j, v_k)$$

Module $|\vec{v}| = \sqrt{v_i^2 + v_j^2 + v_k^2}$

Vector operations

The **scalar multiplication** of a vector returns a vector which components have been multiplied by the scalar.

$$\alpha\vec{v} = (\alpha v_i, \alpha v_j, \alpha v_k)$$

Addition between vectors is done by adding each component to its correspondant.

$$\vec{v} + \vec{p} = (v_i + p_i, v_j + p_j, v_k + p_k)$$

The **scalar product** of two vectors returns a scalar.

$$\vec{v} \cdot \vec{p} = |\vec{v}| \cdot |\vec{p}| \cdot \cos(\theta)$$

$$\vec{v} \cdot \vec{p} = (v_x\hat{i} + v_y\hat{j} + v_z\hat{k})(p_x\hat{i} + p_y\hat{j} + p_z\hat{k})$$

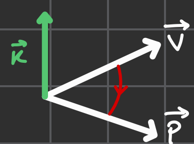
The different axis components cancel each other because the axes are perpendicular to each other and the cosine is zero.
If two vectors are **perpendicular**, their **scalar product** will be **zero**.

The cross-product of two vectors returns a vecher which is perpendicular to the plane formed by the two vectors.

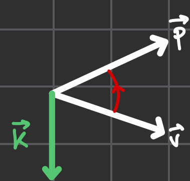
$$\vec{v} \times \vec{p} = \underbrace{|\vec{v}| \cdot |\vec{p}| \cdot \sin\theta}_{\text{Module of the resulting vector}}$$

The direction is determined by the direction in which we're going.

$$\vec{K} = \vec{V} \times \vec{p}$$



Clockwise:
vector goes up



Counter-clockwise:
vector goes down

$$\vec{V} \times \vec{p} = (V_x\hat{i} + V_y\hat{J} + V_z\hat{k}) \times (p_x\hat{i} + p_y\hat{J} + p_z\hat{k}) =$$

$$= V_xP_y\,\underline{\hat{i}\times\hat{J}} + V_xP_z\,\underline{\hat{i}\times\hat{k}} + V_yP_x\,\underline{\hat{J}\times\hat{i}} + V_yP_z\,\underline{\hat{J}\times\hat{k}} + V_zP_x\,\underline{\hat{k}\times\hat{i}} + V_zP_y\,\underline{\hat{k}\times\hat{J}}$$

The highlighted valves determine the vector's direction /sign.
If two vectors are parallel, their cross-product will be zero.

Exercise

$\vec{A}\,(2,-3,1)$

$\vec{B}\,(-4,-3,2)$

$|\vec{A}|, |\vec{B}|$?

$\vec{A}\cdot\vec{B}$?

θ ?

$$|A| = \sqrt{4+9+1} = \sqrt{14}$$

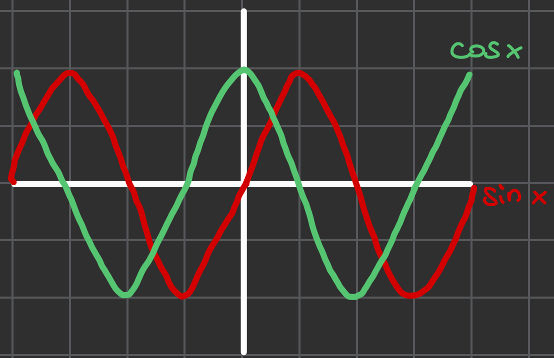
$$|B| = \sqrt{16+9+4} = \sqrt{29}$$

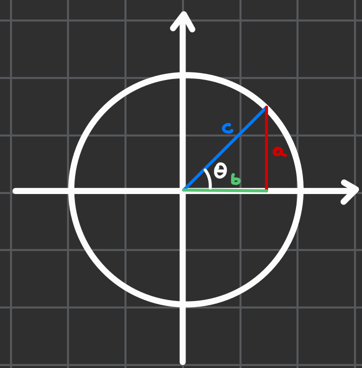
$$\vec{A}\cdot\vec{B} = 2\cdot(-4) + 9 + 2 = 3$$

$$\vec{A}\cdot\vec{B} = |A||B|\cos\theta$$

$$\cos\theta = \frac{\vec{A}\cdot\vec{B}}{|A||B|} = \frac{3}{\sqrt{14}\sqrt{29}}$$

Angle properties

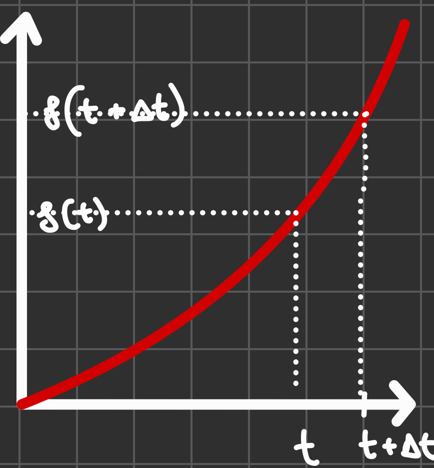




$$b = c\cos\theta$$
$$a = c\sin\theta$$

Differential calculus is a tool used in physics when dealing with **continuous variations**.

$$\lim_{t \to a} f(t) = L$$



Let's consider a variation $\Delta f = f(t+\Delta t) - f(t)$

A derivative is then computed as $\lim_{\Delta t \to 0} \frac{\Delta f}{\Delta t}$

$$\frac{df(t)}{dt} = \frac{f(t+\Delta t) - f(t)}{\Delta t}$$

Exercise

Find the value of the derivative of the function.

$$f(t) = t^2$$

$$f(t+\Delta t) = (t+\Delta t)^2 = t^2 + \Delta t^2 + 2t\Delta t$$

$$f(t+\Delta t) - f(t) = \Delta t^2 + 2t\Delta t$$

$$\frac{f(t+\Delta t) - f(t)}{\Delta t} = \frac{\Delta t^{\cancel{2}} + 2t\cancel{\Delta t}}{\cancel{\Delta t}} = \Delta t + 2t$$

$$\lim_{\Delta t \to 0} \Delta t + 2t = 2t$$ ☺