# Lecture 1 : INTRODUCTION TO PHYSICS



* Why there are no mammals larger than elephants or whales and smaller than mouses ?

— Perhaps this is not the question you asked yourself when you decided to follow this course. Yet, by addressing this question I will try to illustrate how science works and how you will learn to address questions through scien

- Fundamental questions requires fundamental understanding - In other words basic laws. Let's use our basic laws (prior knowledge) and imagination to answer our question.

* However to answer a question precisely we need to formulate it precisely (precisely = quantitatively):

* Is there a relationship (math form) between the Metabolic rate and the mass of mammals ?

* math. relationship ~~requires~~ relates
Measurable quantities ← precise definitions needed

$P \equiv$ metabolic rate $= \frac{\text{Energy}}{\text{Unit Time}}$ ← Food procurement rate

$M \equiv$ mass — You may have a feeling of what mass is (through weight). We'll come to the exact definition in a future lecture

— Knowledge and Hypotheses:

1) * Same cells and constituent material in all the mammals

**Hp.1**: Same density, $\rho$, in all mammals

$\Longrightarrow M = \rho V$ $\qquad V \equiv$ volume

Mass is proportional to the volume

2) * Body temperature is constant in mammals
* Food is not converted into mass, but into energy (proteins, sugar, ... oxidation) spent to live (internal motion of organs), to move, etc.
* Movements → Friction → Heat
Heat dissipated through the SURFACE (Temp = const)

To keep ~~you~~ themselves alive

Metabolic rate ÷ Surface

[~~Already~~ quite some input from basic laws of physic here. → Answers to fundamental questions requires fund. knowledge]

In summary:

Mass ÷ Volume
Metabolic Rat ÷ Surface

* The relationship between mass and metabolic rate is related to the geometry of the space

× Elegant!
× Philosopher: So elegant, it must be true!
× Scientist: Is it true?

Make the relationship a bit more quantitative –

$\boxed{\text{Hp. 3}}$ : spherical mammals of radius $R$

PIG COW WHALE

$$\text{surface} = 4\pi R^2 \div R^2$$
$$\text{volume} = \frac{4\pi}{3} R^3 \div R^3$$

$$\Rightarrow P \div R^2 = (R^3)^{2/3} \div M^{2/3}$$

We have found a power law

$$\boxed{P \div M^{2/3}}$$

* There is a number of consequences to this law that we can list –

– Power (consumption) per unit cell ∝ Power/Mass

Cell metabolic rate in mammals $\doteq \frac{P}{M} \doteq M^{-1/3}$

$$P(\text{cell}) = \frac{1}{\sqrt[3]{M}}$$

Although the cells are all identical, the power consumption/cell is smaller in big mammals

* Big mammals ⟹ more efficient usage of ~~a cell~~ the energy

* Mammals too small cannot survive against more efficient ways of organizing life ⟶ × Insects
~~Monocell~~
× bacteria
× viruses

WE HAVE FOUND A REASON FOR A LOWER LIMIT TO THE SIZE OF MA[MMALS]

There seems to be no upper limit, though –

However: total power consumption grows with mass $P \div \sqrt[3]{M^2}$

E.g. Man $M = 100\,kg$

Elephant $M = 1000\,kg$

$$\frac{P_{\cancel{Eleph}}}{P_{Eleph}} = \sqrt[3]{\left(\frac{1000}{100}\right)^2} = \sqrt[3]{10^2} = \sqrt[3]{100}$$

$$\sim 5$$

→ Elephant need to eat about 5 times what a man eat !

→ There is a problem ~~of~~ with food procurement – BIG SIZE MAMMALS DISFAVOURED

(~~AND~~ IT WORKS FOR REPTILES TOO THINK OF DINOSAUR'S EXTINCTION)

## An aside

- The power consumption of human being is on the average ~ 100 W (about 1 bulb lamp) → FOOD ONLY

- However: The total power used by "civilized" man is ~~about~~ 1 kW including – electric power for industry, services (hospitals), oil for transportation, etc.

  * Power consumption TERNA.IT (excludes fuels for transportation) ~ 40 GW
  * Inhabitants in Italy 50 M

* ~~Human~~ Human beings ~~have a~~ uses natural resources as if their mass was:

$$\frac{M_{\text{civilized man}}}{M_{\text{man}}} = \left(\frac{P_{\text{civil.}}}{P_{\text{man}}}\right)^{3/2} = 10^{3/2}$$

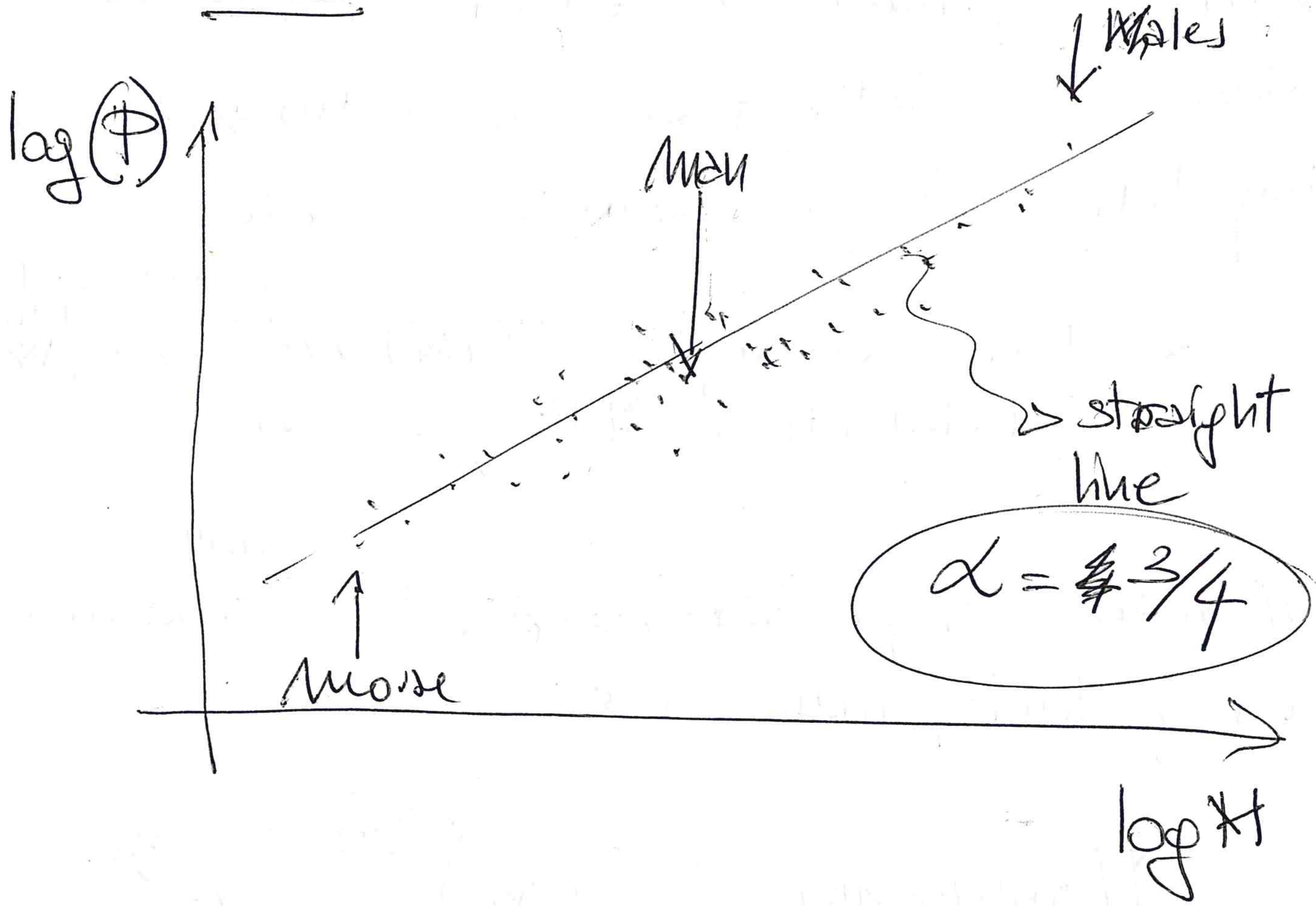
$$= \sqrt[2]{10^3} = \sqrt[2]{1000} = 30$$

* Equivalent mass of a man ~ 3 tons !!!
⟹ Mammals of this size do not survive much!

So far, so good . . . .
but is this all true and consistent
with observations?

[TEST OF ALL KNOWLEDGE IS EXPERIMENT]

— Data




$$P \doteq M^{2/3}$$

$$\log(P) \doteq \log(M^{2/3}) + \cancel{\log}\ \mathrm{const}$$

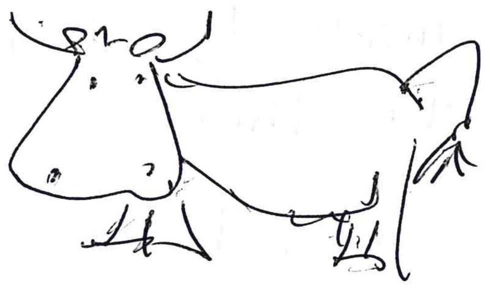
$$\log(P) \doteq \cancel{2/3}\ \log M + \mathrm{const}$$ STRAIGHT LINE

× Our model does not exactly fit data
($\alpha = 3/4$ , while we found $\alpha = 2/3$)

* The prediction of a power law is correct
* General conclusions holds
* Some hypothesis must be adjusted/reviewed

* Suspects ?

"Mammals are not spherical!", you may say



COW : SIDE VIEW

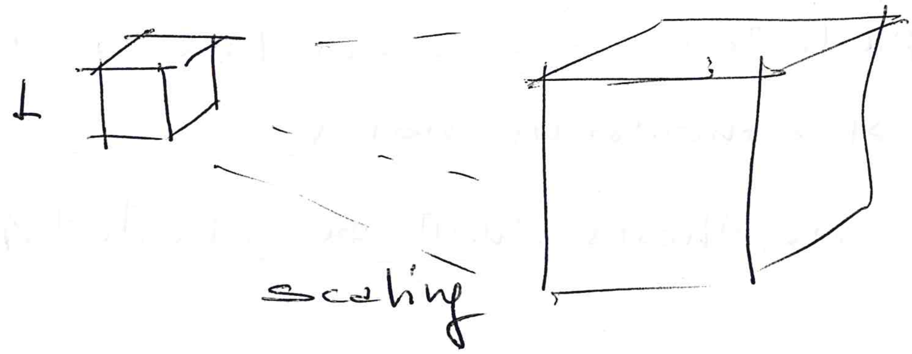
WHALE SIDE VIEW

• However, as we said, the relationship we found is related to the geometry of the space

$$\text{Metabolic rate} \div \text{SURFACE}$$
$$\text{Mass} \div \text{VOLUME}$$

As long as an object has a characteristic scale length $L$ ($R$ in our simplified model), the surface scales with $L^2$ and the volume with $L^3$

Let's check this on a cube:




$S \div L^2$

$V \div L^3$

- It works for spheres and cubes, it must work for any shape! Indeed, we can think of a generic shape as made by many little cubes, one next to the other
- the application of a scale factor to the shape is equivalent to scale all the cubes

$\Longrightarrow$ GENERAL VALIDITY OF SCALING LAWS

no

There are several applications of this

Example: Dose of DRUG to a child and an adult should scale as the height (linear dimension) to the 3rd power, if you wished to keep the same concentration of DRUG in the blood (volume)

~~what~~

* Can it be that we ~~have~~ live in a space with more than three spacial dimensions?

$$\cancel{rat}\ \frac{\text{surface}}{\text{volume}} \cancel{\theta} = \frac{3}{4}$$

⟶ Almost true ⟵

The exact analysis cannot ignore the internal structure of mammals

- Energy distribute to cells by a network (carollo circolatory system)
- Complexity of the network grows with mammal size
- Efficiency gain with mammal size slightly lower than predicted by our simple geometry ~~law~~ (scaling) laws

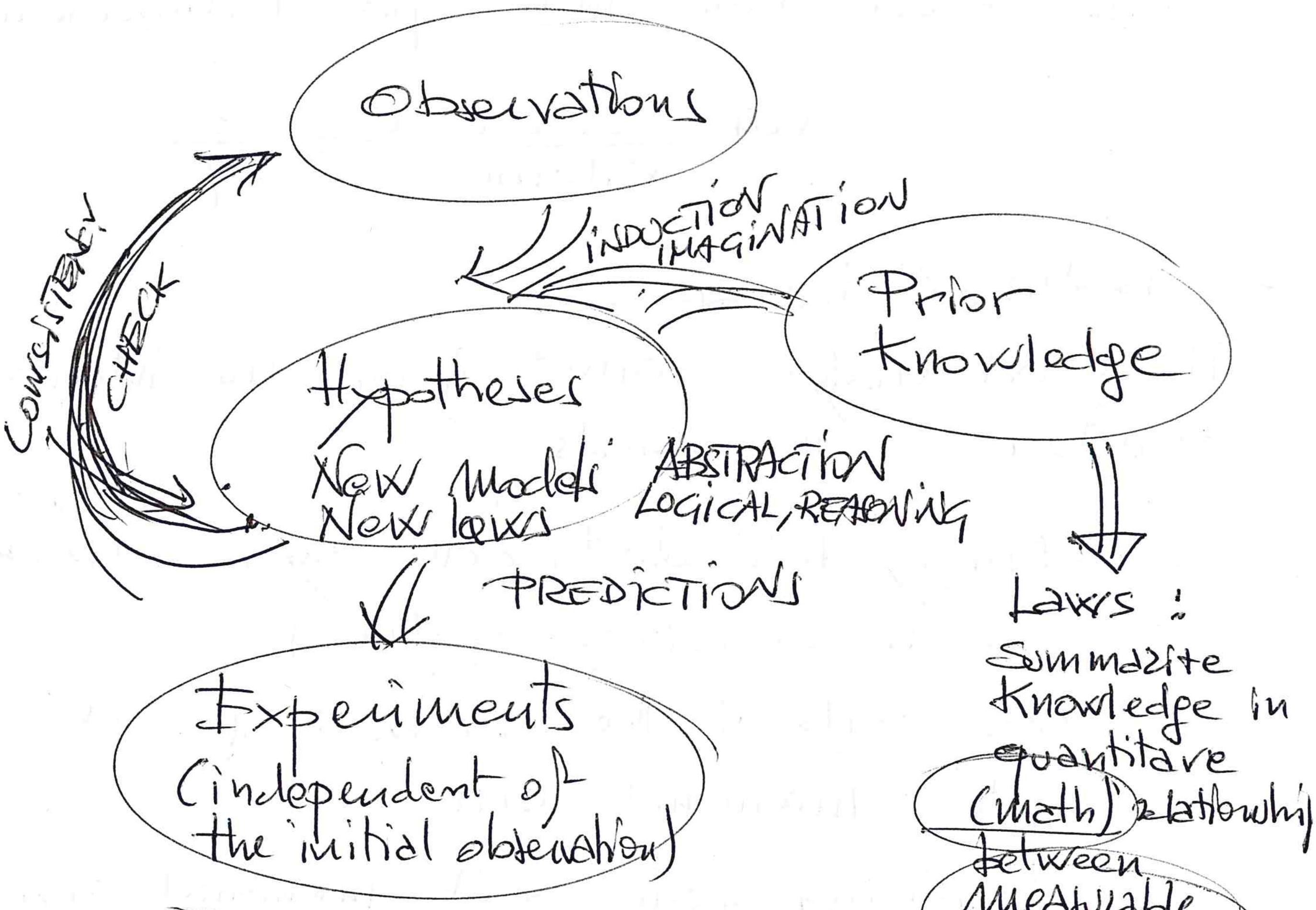
The internal structure adds one dimension to the problem

$$2 \to 3$$
$$3 \to 4$$

* INFINARE $\vec{F} = m\vec{a}$

TAKE AWAY FROM THE EXAMPLE : SCIENCE AT WORK






TEST OF ALL KNOWLEDGE IS EXPERIMENT

Needs :

* Math language [Keep it simple in this course : minimal use of calculus ]

* Precise definition of measurable quantities

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Final NOTE : Though the example is informative $P \div M^{2/3}$ is not a physics law. It's a mathematical relationship derived from some laws. Physics laws do not simply relate things, but ~~...~~ contain dynamical info