Evolution of Physics
by Einstein and Infeld, and
the Machine, Mechanical, and Mechanism in the Sciences

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The purpose of this write up is fourfold:

a) to provide an insight into the connections between the concepts denoted by the terms machine, mechanical, and mechanism in scientific inquiry,
b) to explore the connections between mathematics, philosophy, science, and technology in Ancient Greece, especially as illustrated in Archimedes,
c) to use both (a) and (b) shed light on the use of the expression "mechanical view" in *The Evolution of Physics* by Einstein and Infeld, and
d) to use (a)-(c) in pointing to possible math-science curriculum for that begins with secondary education, and proceeds to the strand of General Education at the Bachelor's level, and will be of value as preparation for the reading of Einstein and Infeld, as well as researchers and research students in mathematics and science to understand the foundations concepts and ideas of ontology and epistemology that inform their practice.

1. GENERAL EDUCATION AND SPECIALISED EDUCATION

The curriculum for class 1 to class 10 in school education is for ***General Education.*** In contrast, the curriculum for a PhD program, and the curriculum for a professional program such as law or medicine, is for ***Specialised Education***.

A learner who registers for the a PhD program or professional program is expected to pursue further learning in physics, and pursue a career related to that program. Under normal circumstances, we do not the majority of those who have a PhD in physics or a MBBS to choose a career in history or philosophy. There are no such career expectations for a General Education Program.

A Bachelor's Program in mathematics, the sciences, and the humanities is a combination of General Education and Specialised education. The curriculum for such programs do have a responsibility to prepare students for higher education in the subjects that the students major in, but they also have a responsibility to prepare students 'become educated' in such a way they have better preparation to meet the challenges in their personal lives, public lives, and any career they choose in their life after the Bachelor's program. subsequent lives.

A few students who receive a Bachelor's in physics proceed to pursue a Master's program in physics or choose careers that call for specialisation in physics, but the bulk of them do not. It is important that the curriculum for a Bachelor's in physics is designed to keep this in view, so that what they learn in the program is of value to them in their life after their degree.

2. EVOLUTION OF PHYSICS IN A PROGRAM FOR GENERAL EDUCATION

If I were asked to choose a single book for physical sciences in an bachelor's program, I would without any hesitation choose *Evolution of Physics* by Einstein and Infeld. The ideas presented in this book are fundamental to the understanding of the nature of scientific knowledge and inquiry, needed in both Specialised Education in physics, and General Education in any bachelor's program.

However, for students to understand the ideas in this book, they need to have prior preparation. I see that preparation along the following strands:

Strand 1: The preparation to understand the last chapter of the book, titled Physics and Reality. (I am attaching a copy pasted extract of this chapter. Do take a look.)

Strand 2: The preparation to understand the concept of the 'mechanical view', in the first two parts titled "The Rise of the Mechanical View" and "The Fall of the Mechanical View", and to understand how the concepts of Field, Relativity, and Quanta in the third and fourth parts are not built in terms of a mechanical view.

Strand 3: The history of the evolution of the different concepts discussed in the book. For instance, to understand classical mechanics, it is not sufficient to understand the concept of mechanical and machine in classical mechanics, mechanical engineering, as well as the concept of mechanism in biology and the concept of mechanistic in philosophy. It is also necessary to understand the concepts of force, vector, velocity, acceleration and displacement.

Einstein and Infeld do not tell us clearly what they mean by 'Mechanical View'. We need to figure out what they have in mind by making guesses on the basis of various remarks in the first two parts of the book, and comparing it with the field concept, relativity, and quanta in parts 3 and 4. But even that may not be sufficient for a science student.

At the end of Part 1 "The Fall of the Mechanical View", in the last chapter "Ether and the Mechanical View" Einstein and Infeld say

> "A mechanical construction means, as we know, that the substance is built up of particles with forces acting along lines connecting them and depending only on the distance. In order to construct the ether as a jelly-like mechanical substance physicists had to make some highly artificial and unnatural assumptions. We shall not quote them here; they belong to the almost forgotten past. But the result was significant and important. The artificial character of all these assumptions, the necessity for introducing so many of them all quite independent of each other, was enough to shatter the belief in the mechanical point of view.
>
> But there are other and simpler objections to ether than the difficulty of constructing it. Ether must be assumed to exist everywhere, if we wish to explain optical phenomena mechanically. There can be no empty space if light travels only in a medium.
>
> Yet we know from mechanics that interstellar space does not resist the motion of material bodies. The planets, for example, travel through the ether-jelly without encountering any resistance such as a material medium would offer to their motion."

From this, and many of the preceding remarks, we can guess that the 'mechanical view is the view that heat, electricity, and magnetism are massless fluids, and that light travels through the interstellar space through a similar fluid called ether. But what has this idea to do with the concept of machine?

The clue lies in the connections between the concepts of machines, mechanics, and mechanisms, all of which can be traced back to the physics of Ancient Greece, especially in the work of Archimedes. Hence, following the footsteps of Einstein, Infeld, and Darwin (who outlined the evolutionary history of physics and of life forms), I would like to bring in a general perspective on the evolution of ideas in science by starting with Archimedes.

3. ARCHIMEDIES AS PREPARATION FOR EVOLUTION OF PHYSICS

The physical sciences study inanimate entities, while the biological sciences study animate entities. The branch of physics called ***mechanics*** has two subdivisions: ***dynamics***, which studies forces and bodies in motion,, (e.g., oscillating pendulums, falling stones, planets revolving around stars, …) and ***statics*** which studies forces in equilibrium and bodies at rest.

Among those who have contributed to the growth of mathematics and the sciences, Archimedes is recognised as the greatest mathematician scientist in Western antiquity. The Wikipedia entry on Archimedes, for instance, quotes Eric Temple saying,

> "Any list of the three "greatest" mathematicians of all history would include the name of Archimedes. The other two usually associated with him are Newton and Gauss. Some, considering the relative wealth—or poverty—of mathematics and physical science in the respective ages in which these giants lived, and estimating their achievements against the background of their times, would put Archimedes first"

and it quotes Alfred North Whitehead and George F Simmons saying

> "In the year 1500 Europe knew less than Archimedes who died in the year 212 BCE.
>
> If we consider what all other men accomplished in mathematics and physics, on every continent and in every civilization, from the beginning of time down to the seventeenth century in Western Europe, the achievements of Archimedes outweighs it all. He was a great civilization all by himself."

and Reviel Netz saying

> "…since Archimedes led more than anyone else to the formation of the calculus and since he was the pioneer of the application of mathematics to the physical world, it turns out that Western science is but a series of footnotes to Archimedes. Thus, it turns out that Archimedes is the most important scientist who ever lived."

Given these remarks, it stands to reason that we begin the preparation to read *Evolution of Physics* with Archimedes. There are two things that Archimedes is famous for. One of them is Archimedes' principle in ***fluid mechanics***. The other is his contributions to the study of ***simple machines***. As the Wikipedia entry on Simple Machines puts it,

> "The idea of a simple machine originated with the Greek philosopher Archimedes around the 3rd century BC, who studied the Archimedean simple machines: lever, pulley, and screw. He discovered the principle of mechanical advantage in the lever. Archimedes' famous remark with regard to the lever: "Give me a place to stand on, and I will move the Earth," ... expresses his realization that there was no limit to the amount of force amplification that could be achieved by using mechanical advantage." (https://en.wikipedia.org/wiki/Simple_machine)

As the Wikipedia entry on Mechanism (engineering) puts it,

> "In engineering, a mechanism is a device that transforms input forces and movement into a desired set of output forces and movement. Mechanisms generally consist of moving components which may include:
>
> Gears and gear trains;
> Belts and chain drives;
> Cams and followers;
> Linkages;
> Friction devices, such as brakes or clutches;
> Structural components such as a frame, fasteners, bearings, springs, or lubricants;
> Various machine elements, such as splines, pins, or keys.

The German scientist Franz Reuleaux defines machine as "a combination of resistant bodies so arranged that by their means the mechanical forces of nature can be compelled to do work accompanied by certain determinate motion". In this context, his use of machine is generally interpreted to mean mechanism. (https://en.wikipedia.org/wiki/Mechanism_(engineering)

Both shed light on the mechanical view in the physical sciences, as well as the concept of 'mechanisms' in biological sciences.

4. ARCHIMEDES AND FLUID MECHANICS

Chapter 10 'Gravitation' in the NCERT textbook for Science has a section on buoyancy. It also discusses the Archimedes principle, and the story of him jumping out of the bath tub, and running out naked, shouting Eureka, a story that is as familiar as the story of an apple falling on Newton's head.
"Archimedes' principle states that the upward buoyant force that is exerted on a body immersed in a fluid, whether fully or partially, is equal to the weight of the fluid that the body displaces. Archimedes' principle is a law of physics fundamental to fluid mechanics. It was formulated by Archimedes of Syracuse" (https://en.wikipedia.org/wiki/Archimedes%27_principle).

It is important to make a note of the following points:

1) As this statement makes clear, the concept of force as that which causes a displacement existed in the ancient times. Galileo replaced this concept with the concept of force as that which causes acceleration.

2) The methodological strategy of formulating scientific laws in terms of the relation of equality, and formulating them in terms of the mathematical formalism of equations of the form X = Y, existed in Ancient Greece.

3) Equations of the form X = Y is understood in terms of continuous quantities in physics, in contrast to the use of the term chemical equations to refer to statements of the form X → T in chemistry (see https://en.wikipedia.org/wiki/Chemical_equation)

4) The concept of displacement in classical mechanics is that of continuous change. In contrast, the concept of displacement in fluid dynamics is discrete (with only two values), granted that we can measure the volume of the fluid displaced in continuous quantities.) (I am saying this to highlight the point that laws in the physical sciences can be either gradient/continuous or categorial/discrete, formulated as 'X is equal to Y' with the symbol "=" or as "X changes to Y" with the arrow symbol "→" in chemical equations and implications in propositional calculus. By and large, science students, science educators, and science researchers do not appear to be sensitive to the existence of laws that go beyond equations in physics to the other kinds of laws needed outside of physics, even within physics.

5) In Archimedes' Principle, for the fluid to exert an upward force and for the solid body to exert a downward force, the two bodies have to be in contact, not at a distance. This idea of ***action and reaction requiring contact*** (as in the case of billiard balls) dominated all forms of scientific inquiry, and continues to do so, even in field theories, making scientists uncomfortable about ***action at distance***. (A great deal of the evolution of theoretical linguistics can be understood as ways of avoiding laws that imply action at distance.)

What I have articulated in (1)-(5) is for undergrad and grad students. For school students, we may use the concept of buoyancy to construct inquiry tasks that focus attention on the following:

Phenomenon 1: What explains the asymmetries in the observational generalisations on a solid object floating on a liquid? (e.g.,

> Puzzle A: a lump of metal sinks if placed on the surface of water, but a lump of wood sinks.)
>
> Puzzle B: Both metal vessels and wooden vessels float when placed on the surface of water.

Given A and B, how do we formulate laws on floating vs sinking in a fluid?

Phenomenon 2: What explains the asymmetries in the observational generalisations on the upward and downward motion of solid objects immersed in a fluid? E.g. Both chunks of metal and metal vessels sink (moves down) when fully immersed, but a wooden object, whether a chunk of a vessel, moves up when held half way down in a bucket of water.)

How do we formulate laws on upward and downward motions in a fluid?

To spice up phenomena 1 and 2, we can add the contrast between the behaviour of an empty glass bottle and a glass bottle filled with water.

Notice that these tasks focus the learner's attention to

a) Properties/behaviour of substances (wood vs metal)
b) Properties/behaviour of objects (wooden and metal vessels), and
c) Motion in air (aerodynamics) and motion in fluid (fluid dynamics.)

Classical mechanics ignores the substances through which an object moves. It also ignores the volume of the object. (A stone and the earth are point masses for Newton.) It is important for students to be sensitised to the bold idealisation (decontextualization) to get to the kinds of abstractions needed in mathematics and physics, so that they can ask themselves how they can proceed to construct laws in the biological sciences through idealisation to create abstractions.

5. ARCHIMEDES AND THE MECHANICS OF MACHINES

The simple machines that the ancient Greeks investigated included the lever, winch, pulley, wedge, screw, pump, water wheel, water mill and wind mill. A great deal of mechanics in Ancient Greece was the Mechanics of Machines. It is not surprising that this shaped the mechanical view of reality in not only in the physical sciences, but also in the concept of mechanisms in biology.

From among different simple machines, we will pick Archimedes' work on the lever to shed light on how his work shaped the nature of science and scientific inquiry in the physical sciences.

Rather than providing my own exposition of some of the important points emerging from the work on the lever, I will simply copy paste a few extracts from the internet.

> "Archimedes explained the underlying ratios of force, load, and distance from the fulcrum point, and provided a law governing the use of levers. In Archimedes's formulation, the effort arm was equal to the distance from the fulcrum to the point of applied effort, and the load arm equal to the distance from the fulcrum to the center of the load weight. Thus established, effort multiplied by the length of the effort arm is equal to the load multiplied by the length of the load arm—meaning that the longer the effort end, the less the force required to raise the load. Simply put, if one is trying to lift a particularly heavy stone, it is best to use a longer crow bar, and to place the fulcrum as close as possible to the stone or load." (https://www.encyclopedia.com/science/encyclopedias-almanacs-transcripts-and-maps/archimedes-and-simple-machines-moved-world).

"If a simple machine does not dissipate energy through friction, wear or deformation, then energy is conserved and it is called an ideal simple machine. In this case, the power into the machine equals the power out, and the mechanical advantage can be calculated from its geometric dimensions.

Although each machine works differently mechanically, the way they function is similar mathematically. In each machine, a force F_{in} is applied to the device at one point, and it does work moving a load, F_{out} at another point. Although some machines only change the direction of the force, such as a stationary pulley, most machines multiply the magnitude of the force by a factor, the mechanical advantage

$$MA = F_{out} / F_{in}$$

that can be calculated from the machine's geometry and friction." (https://en.wikipedia.org/wiki/Simple_machine)

I would also recommend skimming through, if not reading *A History of Mechanical Inventions* (1929) by Abbot Payson Usher. Given below are a few extracts that I find illuminating. I have colour coded (in blue) some parts that call for particular emphasis.

"Science arises out of practical experience. It is an attempt to communicate acquired experience with the maximum economy of statement. Science, therefore, appears only after considerable accumulations of experience, and for a long period it is merely a commentary upon the general practice of the arts and crafts involved. Not until substantial achievements in analysis have occurred does science begin to exert a creative influence upon the processes of discovery and invention. Carefully considered, the early treatises upon the mechanical sciences are an important part of the historical evidence bearing upon the technical proficiency of the early period, but such material must be used with caution because for many centuries, practice was in advance of theory." (p 168, Chapter V)

"The objects of science lead naturally to generalization and simplification. The phenomena as perceived are analyzed into simple components and these in turn are referred to one or more principles. In so far as these accomplishments are largely empirical no particular problems arise. Both general and simplified data are closely related to experience, and, though results may not be great, they are not likely to be vitiated by positive errors. The attempts at generalization, however, lead to the recognition of connections among the various sciences and between the sciences as a group and the broader problems of philosophy. It is at this stage that complications arise in Greek achievements in the mechanical sciences. Interest in the problems of mechanics developed from several directions. The problems of equilibrium or statics were implicit in the five "simple" machines, some of which had long been in use, while others were coming into active use contemporaneously with the development of science. The problems of dynamics, however, arose most conspicuously in connection with astronomy. Furthermore, the extension of analysis to the mechanical fields was in part an outcome of the endeavor of the Peripatetic school to formulate a comprehensive body of philosophic and scientific truth. The particular sciences took form, therefore, when there was active discussion of the purely general problems of the relations of the sciences to each other. The status of the sciences in relation to each other and the methods appropriate to scientific inquiry were inevitably influenced by the general discussion of the nature of truth.

Both Platonists and Aristotelians inclined strongly toward a concept of truth as absolute and eternal, though isolated passages occur that might be interpreted as a recognition of a doctrine of relativity. Other schools held doctrines that challenged the concept of absolute truth. But the primary object of philosophy came to be defined as the discovery of the eternal truths of nature, and the task of the sciences was appropriately defined as the construction of hypotheses that would present the phenomena of nature as manifestations of the eternal truths.

This general concept of the task of science was in the mechanical sciences largely responsible for the subordination of experimentation to logical demonstration by means of mathematical principles. It is for this reason, that the statement is frequently made that experimental methods were not used by the Greeks. The error of this statement is now widely recognized, though the mistake is still frequently encountered. Experiments were made, but with objectives that were more limited than in modern science. With the early scientists, experimentation was incidental and casual. Not until the close of the Middle Ages were the mechanical sciences definitely placed upon a foundation of verifiable experience derived from systematic and progressive experimentation. Until then the mechanical sciences of a formal character rested upon supposedly self-evident axioms, or upon primary metaphysical concepts. Attention was thus directed toward logical demonstrations and toward mathematical theorems that involved pure reasoning rather than toward experimental study of the phenomena. Formal mechanics was thus restricted in antiquity to the demonstration of the principle of the lever and the manifestations of that principle in the "sense, the classic demonstrations are accompanied by carefully devised experiments, though we are not likely to think of them as such because they do not lead to any revision of the findings of common sense. The emphasis is placed upon intuitive perception and the symmetry of the arrangement, so that it becomes a demonstration of why the phenomena assume the form they do. It is not an experimental analysis of how the phenomena take place." (pp 169-172, Chapter V)

Excerpt From: Usher, Abbott Payson;. "History of Mechanical Inventions". Apple Books.