ALBERT EINSTEIN (1879 – 1955)

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1. Scientific Work

The works which were to make Albert Einstein famous throughout the international scientific community were first published in *Annalen der Physik* in 1905 and 1906. This collection comprises six articles, submitted by the author for publication in 1905, when he was just 26 years old. Some of these works anticipate what has come to be considered by science historians, along with quantum theory, as the scientific revolution of the twentieth century. Further revolutionary articles were published—also in *Annalen*—from 1907 on, culminating with the article he published in the journal in 1915, setting the bases for a new theory of gravity.

During the last third of the nineteenth century, classical physics, based on the works of Galileo and Newton, was showing signs of weakness in the face of certain phenomena related to the mechanical view of the world viewed from a novel perspective based on the concept of energy. The result was a bitter dispute between “atomists” and “energists”. But where the most profound conceptual difficulties arose was in the attempts to harmonise Maxwell's electro-magnetic theory and the principles of Newtonian physics, an incompatibility that was resolved by Einstein’s bold proposals, propounded in one of his celebrated articles of 1905. From his earliest work, Einstein showed a great intuitive capacity to discern physical laws, a power of concentration that enabled him to shut himself off whenever he needed, an unusual sharpness in thinking up “mental experiments”, and above all a broad and up-to-date knowledge of the science of his time.

After he had concluded his work on relativity—successfully confirmed both in the calculation of the perihelion shift of Mercury and the eclipse of sun in 1919—and following the publication of other highly important articles on the interaction between light and matter and on the fundaments of quantum physics, Einstein devoted his efforts to searching for a unification of the classical fundamental forces of nature: it was a frustrated aspiration which was to occupy much of the rest of his life, and which still today continues to be a challenge for twenty-first century physics.

1.1. Physics before Albert Einstein

Throughout the nineteenth century, physics gradually consolidated its position as an experimental and exact science; it was institutionalised as an activity carried out by scientists, who by then had been given that name; and it reached the classrooms of universities and secondary schools as a discipline to be taught and learnt separately from the philosophical and theological disciplines to which it had once been allied. Thus, a profession was created from which people could earn a living and even achieve some social prestige.

When Albert Einstein was born in 1879, experimental work still took precedence over theoretical grounding. The equivalence between heat and mechanical work was known, associating heat with energy phenomena, although there remained discrepancies over whether the heat was a substance, a type of energy or a physical process; light was now considered to be a form of wave motion, the battle having been won against those who argued that it was “corpuscular”; The discovery of the reciprocity between magnetism and electrical currents at the beginning of the century had led to Maxwell's electro-magnetic theory; and many experiments were being carried out regarding the production of radiation in a vacuum: Röntgen discovered X-rays the same year, 1895, in which Lorentz propounded his electron theory, confirmed in experiments by Thomson and Wien at the end of the century; Becquerel discovered the radioactive behaviour of uranium (1896).

Besides academic teachings, which he followed irregularly, Einstein devoted his time to studying the works of Maxwell (who had died the same year as Einstein was born), Hertz, Kirchhoff and Helmholtz, thus providing himself with a grounding in the latest developments in physics. At the recommendation of his lifelong friend, Michele Besso, he read the work of Ernst Mach, who, along with Newton, Maxwell, Lorentz and Planck, Einstein considered to be one of his precursors.

1.1.1. Classical Physics

The pillars of what was known as *classical*, or *Newtonian* physics, were founded on the works of Galileo Galilei (1564-1642), *Dialogues Concerning Two New Sciences*, published in Leiden (Netherlands) in 1638, and the *Mathematical Principles of Natural Philosophy* by Isaac Newton (1642-1727),

published in London in 1687.
Galileo’s work, translated into English in 1661, contains the first formula for the free fall of bodies, setting the base for his experimental and geometric study. This publication was crucial in surmounting Aristotle’s' disquisitions on movement and laying the foundations of scientific knowledge on observation, experimentation, measurement and mathematical formulation.

Newton provided a mechanical vision of the world based on the laws of dynamics and achieved the first scientific synthesis culminating with the establishment of the law of universal gravity, which put paid to the old differentiation between the earth and the heavens as worlds governed by different principles. After Newton it was only possible to speak of a single universe and a single physics.

In the last third of the nineteenth century James Clerk Maxwell (18311879) tackled the question of the mathematicisation of electromagnetism which had arisen from the initial experiences of Oersted and Ampére, continued by Faraday who introduced the concept of the electrical field and the magnetic field to delimit the areas of influence of the forces from electrical charges and currents, for the former, and those related to magnets for the latter.

In his theory of electromagnetism, Maxwell managed to relate the properties of magnets, electrically charged bodies and electrical currents, and he also predicted the propagation of electro-magnetic phenomena by means of waves travelling at the speed of light, considered from then on to be electro-magnetic disturbance. This grouping together in a single theory of the electrical, magnetic and optical behaviour of matter represented the discovery of a new scientific synthesis as transcendental as Newton's. Both were pillars of classical physics, but so different in nature that the contradictions between them rocked its very foundations, leading to a new form of physics based on the principles established by Planck and Einstein.

1.1.2. Doubting Newton

Ernst Mach (1838 – 1916), the Austrian physicist and philosopher, contributed to the mathematical formalisation of optical and mechanical phenomena and above all certain phenomena related to wave propagation, such as his study on the Doppler effect and the propagation of sound. But where he exercised the greatest influence was as a philosopher, falling into what was known as the “positivist” school for whom only that which we know through sensorial perception has any had scientific validity; his work *Contributions to the Analysis of the Sensations* (1886) was widely read.

He rejected absolute concepts of space and time, which were basic to Newtonian mechanics, considering them to be metaphysical concepts, which were inadmissible for the principle of “economy of thought” which should, in his opinion, underpin any scientific activity. Einstein himself said that Mach's ideas had inspired his first steps towards the theory of relativity, although he soon distanced himself from them. He did not share Mach's beliefs on the fulfilment of the general laws of physics as simple generalisations of experimental results. Rather, he held that these laws, although they can be verified experimentally, have their origin in the mental faculties of individuals, thus positioning himself closer to the philosophy of Kant. His favourite philosopher, however, was David Hume for whom science was constructed on experience and logical/mathematical deduction.

Mach also had an influence on those who rejected the concept of force, as in Newton's dynamics, and the atomism of matter, considering such hypotheses unnecessary and impossible to prove at that time. His followers preferred a concept of energy which had different manifestations, governed by a principle of conservation and by the fact that they could be measured. This challenge to Newtonian mechanics was led by Wilhelm Ostwald (1853 – 1932), at the head of the selfstyled *energists*, who manifested their radical opposition to atomism with the categorical, quasi-Biblical phrase: “Thou shalt use neither images nor similes”.

1.1.3. Crisis in Physics

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At the end of the nineteenth century, Lord Kelvin argued that the basic foundations of physics had been definitively laid”. It was not long, however, before those solid foundations were to be rocked. There were essentially two phenomena which were to put physics in quarantine: blackbody radiation and the electrodynamics of moving bodies.

For physicians a *black body* is a perfect ideal absorbent, capable of swallowing up any electromagnetic radiation which reaches it, and for that reason it is also a perfect transmitter; a small hole in a completely sealed box at any temperature is an example of a black body. If we accept the explanation given by classical physical principles, based on the idea that the energy absorbed or issued corresponds to a process of wave (and therefore continuous) motion, this should lead to a situation known as the *ultraviolet catastrophe*, which—if it were existed—would mean that when we opened the kitchen oven, in which the radiant energy is constantly bouncing off the walls, we would suddenly be hit by a blast of deadly radiation. Fortunately, of course, this does not happen, in contravention of the principles of classical physics.

With regard to the electrodynamics of moving bodies, the facts also contradicted Newtonian explanations. Let us see how Einstein examined the problem in his celebrated article "On the Electrodynamics of Moving Bodies":

"Take, for example, the reciprocal electrodynamic action of a magnet and a conductor. [...] if the magnet is in motion and the conductor at rest, there arises in the neighbourhood of the magnet an electric field with a certain definite energy, producing a current at the places where parts of the conductor are situated. But if the magnet is stationary and the conductor in motion, no electric field arises in the neighbourhood of the magnet. In the conductor, however, we find an electromotive force, to which in itself there is no corresponding energy, but which gives rise—assuming equality of relative-motion in the two cases discussed—to electric currents of the same path and intensity as those produced by the electric forces in the former case". Einstein was surprised by this asymmetry in the description of two apparently reciprocal phenomena, the relative movement of conductors and magnets, with identical results, since the current produced in both cases is the same.

Moreover, if the transformations of coordinates in Maxwell's equations are applied to the relative movements between charges and magnets in accordance with Newtonian mechanics, the theoretical results do not match the phenomena observed. This unexpected electrodynamic behaviour of moving bodies opened further questions for physicists who in Gamow's words "were suffering the angst of metamorphosis from the classical larva to the modern butterfly".

1.1.4. The First Solution

In order to find a solution to the inadmissible ultraviolet catastrophe, Max Planck (1858-1947) was forced to propose the *quantum* hypothesis, which attributed a discontinuous character to the radiation emitted and absorbed.

Thus, very much against his will, he opened up – an irreparable breach in the classic foundations of physics which had always maintained that “nature doesn't jump”. Planck himself was so astonished, that when he presented his ideas to the Berlin Physics Society, he confessed: “This entire issue can be summarised in three words: an act of desperation. Because I have consciously turned my back on nature... A theoretical interpretation therefore had to be found at any cost, no matter how high. [...] The two laws [of thermodynamics], it seems to me, must be upheld under all circumstances. For the rest, I was ready to sacrifice every one of my previous convictions about physical laws”.

At the beginning of his career, Planck shared the ideas of the antiatomists. In his doctoral thesis, read in 1879, the year Einstein was born (the two would go on to profess unconditional admiration and friendship) he opposed the atomic hypothesis of matter on the grounds that it contradicted the principle of conservation of energy: “Nonetheless the success enjoyed to date by the atomic theory”– he wrote–“will eventually be abandoned in favour of the hypothesis of the continuity of matter”. Little could he have dreamt that not only would he one day be forced to accept the discontinuity of matter, but that he himself would propose the discontinuity of energy!

The “quantum” led to quantum mechanics, of which Heisenberg's indetermination principle forms the cornerstone of all the uncertainty regarding the measurements of observable sizes, a principle which Albert Einstein challenged throughout his life.

1.2. 1905: the *Annus Mirabilis*

Max Born (1882-1970), one of the leading figures behind quantum mechanics, wrote in Volume 17 of *Annalen der Physik* in which three of Albert Einstein's famous articles were published: “This is one of the most remarkable volumes in scientific literature”. These articles which, together with Planck's theories, helped show the way out of the predicament of fin-de-siècle physics, were:

- “On a Heuristic Point of View Concerning the Production and Transformation of Light”, which introduced the theory of the photon or light quantum.
- “On the movement of small particles suspended in stationary liquids required by the molecular-kinetic theory of heat”, related to Brownian movement, which provided sufficient arguments to leave the atomic

theory of matter definitively settled.
- "On the electrodynamics of moving bodies", where he established the bases for the special theory of relativity.

Another article was published the same year, in Vol. 18:
- "Does the inertia of a body depend on its energy content?", in which he devised the formula which would later come to be written as $E = mc^2$.

And finally, in 1906, two other articles were published, complementing the ones Einstein had published in *Annalen* in 1905:

- "A new determination of molecular dimensions"
- "On the theory of Brownian motion"

The impact these articles have had on the subsequent course of physics amply justify the fact that 1905 is referred to as Einstein's "annus mirabilis". At the time, this 26-year old was, to use his own term, a "venerable federal penpusher", working as a third-class technical expert assistant at the patent office in Berne, with a yearly salary of 3500 francs, enough to allow him to live decorously but without excesses. Until he got the job, the Einsteins (he had married his fellow student at the Eidgenössische Technische Hochschule in Zurich, Mileva Maric (1875-1948) lived off the income they gained by giving private classes.

1.3. General Relativity: a new theory of gravity

Confirmation from experiments that the speed of light in a vacuum, c —the maximum speed known to date for transmitting data—is the same for all inert observers, i.e. those for whom the principle of inertia, as formulated by Newton, is fulfilled, led Einstein to consider that the concept of *simultaneity* was a relative one. Furthermore, the finitude and constancy of c alters the classic notions of space and time, producing effects such as the *dilation of time* and the *contraction of space*, which increase with the velocity, and cannot be reconciled with Newtonian mechanics. Together with the discovery of the relationship between the mass and energy of a given quantity of matter, $E = mc^2$, these phenomena form the surprising and relevant contributions of the special or restricted theory of relativity, governed by the principle that the laws of physics, such as the speed of light, are the same for all stationary observers.

Einstein extended the special theory to accelerated movements and curved trajectories, taking as a reference planetary movement and free fall towards Earth. He thus established his general theory of relativity, essentially based on the *principle of equivalence* between acceleration and gravity, which he considered “the most fortunate idea of my life”. It was certainly his most original idea and the one for which he finally gained the recognition of the scientific community.

Classical physics’ notion of space, as a receptacle which exists regardless of whether or not is has content, and time, as an imperturbable measure of the duration of events, whatever the dynamic circumstances in which they occur, ceased to be valid. According to the general theory of relativity, space-time, as a single whole, is configured by the matter itself: a space-time described with Riemannian, rather than Euclidean, geometry. Despite the change these ideas wrought in the physics of his time, Einstein considered his theories of relativity to be “an evolution, not a revolution, in dynamics”. In answer to a journalist, Einstein summarised his relativist theories as follows: “Time, space and gravity do not exist without matter”.

1.4. Quantum Dilemma: Einstein *vs.* Bohr

To mark Einstein's seventieth birthday, *Albert Einstein: Philosopher-Scientist* was published under the editorship of Paul A. Schilpp, a professor of philosophy and Methodist minister. The work was essentially meant to explain the importance of Einstein's contributions to physics, and his own impressions on his life and work, contained in the “Autobiographic Notes” with which the book begins.

Amongst the prestigious scientists and philosophers who worked on the publication were Niels Bohr (1885-1962), author of the article “Discussion with Einstein on Epistemological Problems in Atomic Physics”, in which the Danish physicist told of the conversations he had held over the years with Einstein regarding the course being taken by atomic physics, currently immersed in a process of development and consolidation. As scientists’ understanding of the constitution of atoms developed, classical physics began to prove increasingly lacking when it came to providing explanations,

Breadth of chest: 87 cm
Arm: 28 cm
Illnesses or handicaps: varicose veins,
flat feet, and excessive perspiration of feet.

Self-portrait

Of what significance is one's existence, one is basically unaware and it should certainly not concern our neighbour. What does a fish know about the water in which he swims all his life?

The bitter and the sweet come from outside. The hard from within, from one's own efforts. For the most part I do what my own nature drives me to do. It is embarrassing to earn such respect and love for it. Arrows of hate have been shot at me too; but they never hit me, because somehow they belonged to another world, with which I have no connection whatsoever.

I live in that solitude which is painful in youth, but delicious in the years of maturity.

On his everyday life (in answer to a reporter from *ABC* during his stay in Spain in 1923):

Well then; I shall satisfy your curiosity. My life is very irregular. Sometimes, when I am concerned with a problem, I do not work for days on end; I go for walks, I pace up and down at home, I smoke, I dream and I think. On the contrary, there are weeks when I don't stop working. But, in general, I go to bed at eleven and get up at eight. As you see, my body and my brain need a long repairing sleep. I rarely go out at night; social life irritates me.

Disillusionment at the mistrust and persecution suffered by some scientists in the United States in the 1950s, Einstein among them:

If I would be a young man again and had to decide how to make my living, I would not try to become a scientist or scholar or teacher. I would rather choose to be a plumber or a peddler in the hope to find that modest degree of independence still available under present circumstances.

To Elisabeth Ley, Stuttgart

September 30, 1920 Dear Miss Ley,

Elsa tells me that you are unhappy because you didn't get to see your Uncle Einstein. Therefore I will tell you what I look like: pale face, long hair, and a modest paunch. In addition, an awkward gait, a cigar—if I happen to have one—in the mouth, and a pen in the pocket or hand. But this uncle doesn't have bowed legs or warts, and is therefore quite handsome; and neither does he have hair on his hands, as ugly men often do. So indeed it is a pity that you didn't get to see me.

With warm greetings from your Uncle Einstein

This is how he saw himself throughout his life

"The physicists say that I am a mathematician, and the mathematicians say that I am a physicist.

I am a completely isolated man and though everybody knows me, there are very few people who really know me."