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Atoms and Radiation

Excerpts from the Inaugural Lecture - 18 April 2013

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RÉFÉRENCE

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1 **At the start of the seventeenth century, German astronomer Johannes Kepler sought to understand a mysterious phenomenon: comet tails, celestial objects claimed to have supernatural properties, always point away from the Sun.**



2 When a comet goes towards the Sun, it resembles hair floating in the wind. But when the comet moves away from the Sun, the tail comes before the nucleus, which seems counter-intuitive. Kepler sought to explain this phenomenon with the following proposition: “A comet’s tail is formed by matter that the Sun’s rays

chase through their impulses outside the comet’s body”¹. At the end of the same century, Dutch physicist Nicolas Hartsoeker, a member of our Académie des sciences, wrote in his *Principes de physique*²: “Commuters are adamant that the Danube is far slower in the morning when the Sun’s rays counter its course than in the afternoon when they aid it”.

3 Of these two scientists, Kepler was at least partially right; Hartsoeker, was only describing an optical illusion. But the two scholars had the intuition of a phenomenon that plays a crucial role in today’s physics: light, and electromagnetic radiation more generally, can act on the atoms and molecules that make up matter.

4 The two words that make up the title of this Chair, *atoms* and *radiation*, represent the core of the physical world with which we are familiar. Light is both a channel for information on our environment and a means of controlling it. It serves as an information channel for astronomers, for instance, who are able to deduce a star’s age from its colour. As a means for action, light can locally provide a determined quantity of energy, as the cutting of materials with lasers illustrates.

5 Matter and radiation are closely linked in the progression of knowledge. Advances in our modelling of the movement of particles and in that of light have gone hand in hand. Thus, in the seventeenth century, Fermat explained the laws of light reflection and refraction – previously set out by Descartes and Snell – thanks to his principle: “Nature always acts through the shortest and simplest paths”. One hundred years later, Maupertuis’, Lagrange’s and Euler’s extension of Fermat’s idea to mechanics gave rise to the principle of least action, which is still highly significant today. At the turn of the twentieth century, the study of the light emitted by an oven allowed Max Planck to lay the foundations of what was to become quantum physics, by providing in particular an explanation of the stability of matter. Fifty years later, Willis Lamb’s highly precise measurements of the structure of atoms led to the development of quantum electrodynamics, the now universally accepted model for describing radiation.

6 Quantum electrodynamics is an extraordinarily precise theory: despite increasingly stringent tests, it has never been called into question. Its success even raises a crucial question: on a fundamental level, are there still any open problems in the science of

atoms and light? In other words, have optics and atomic physics not become technologies at the service of other disciplines?

- 7 I would here like to provide a few answers which prove the full vitality of this research field. We owe this vitality to a device, the *laser*, which actually refers to a considerable variety of tools. It can represent a light-beam sent to reflect on the moon in order to measure the moon's distance from the earth, a light source injected into an optical fibre as a medium for information, or a train of short and intense pulses used to probe chemical reaction dynamics or to initiate the fusion of atomic nuclei.
- 8 This presentation will focus on one of the most spectacular and paradoxical applications of laser, namely the cooling of atom gases. While laser is traditionally associated with the idea of heat, it can also be used to reduce substantially the random movement of a gas' particles and thus to obtain a virtually perfect order, less than a millionth of a degree above absolute zero. The quantum matter that is produced in this way exhibits radically different properties from those of the fluids or solids we encounter in daily life. Interest in this quantum matter extends far beyond the scope of atomic physics specialists. Physicists of condensed matter, chemists, mathematicians and astrophysicists all use it as a source of illustrations and research questions regarding phenomena related to their discipline.

- Inaugural Lecture published by Éditions Fayard and online at www.books.openedition.org/cdf/3301

- The video of the Inaugural Lecture is available online at www.college-de-france.fr on the professor's page.

NOTES

1. Johannes Kepler, *De cometis libelli tres. I. Astronomicus... II. Physicus... III. Astrologicus...*, Augustae Vindelicorum, Augsburg, 1619; translation by H. Flaugergues in *the Journal de physique, de chimie et d'histoire naturelle*, vol. LXXXV, September 1817, p. 193-216.
2. Nicolas Hartsoeker, *Principes de physique*, published in Paris by Jean Anisson, Head of the Imprimerie royale, 1696.

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