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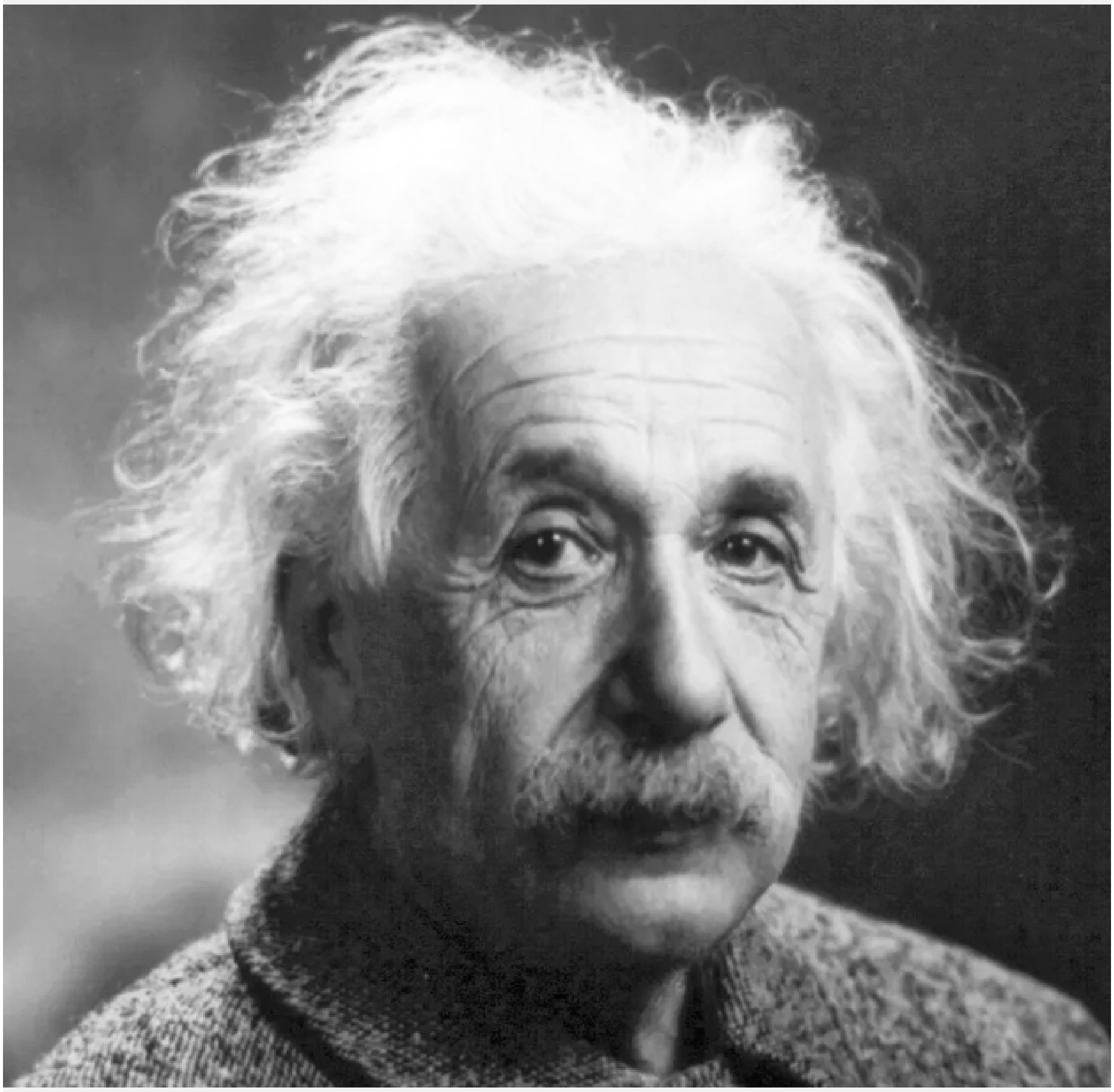
Albert Einstein

Collected Works

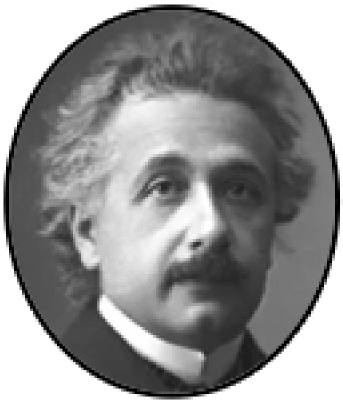


Series Fifteen

The Collected Works of

ALBERT EINSTEIN

(1879-1955)



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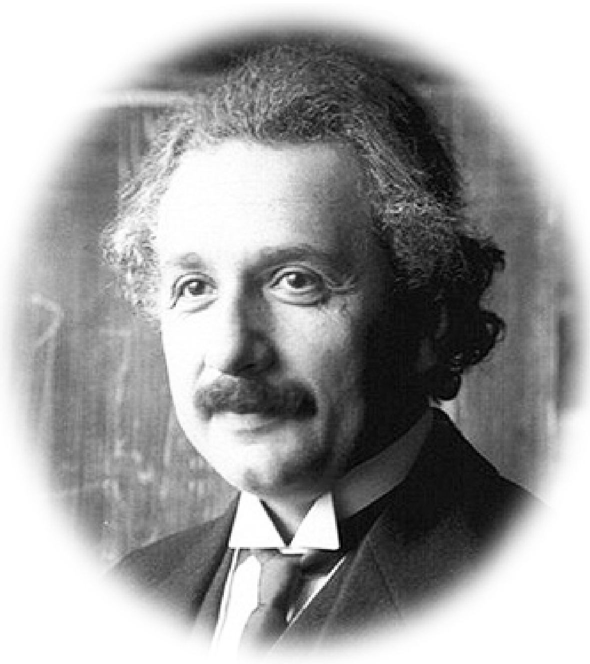

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Annus mirabilis Papers

Ulm, a city in the south-western German state of Baden-Württemberg — Albert Einstein's birthplace

The Albert Einstein Memorial in Ulm, at the site of the birthplace. The house and the district were destroyed in the firebombing of 1944.

Einstein, aged five

Einstein in 1893, aged 14

On a Heuristic Point of View about the Creation and Conversion of Light (1905)

Anonymous translation

In 1900 Einstein graduated from the federal polytechnic school, where he was certified as competent to teach mathematics and physics. His successful acquisition of Swiss citizenship in February 1901 was not followed by the usual sequel of conscription, as the Swiss authorities deemed him medically unfit for military service. He found that Swiss schools appeared to have no use for him, with no offer of a teaching position, in spite applying for almost two years. Eventually, he secured a post in Bern at the Swiss Patent Office as an assistant examiner. The patent applications that landed on his desk for his evaluation included ideas for a gravel sorter and an electric typewriter. It is likely that his work at the patent office had an influence on the development of his special theory of relativity. In time, he would develop revolutionary ideas about space, time and light through thought experiments about the transmission of signals and the synchronisation of clocks — matters that also featured in some of the inventions submitted to him for assessment.

In 1902, Einstein and several friends that he had met in Bern formed a group that held regular meetings to discuss science and philosophy. Their choice of the club's name, the *Olympia Academy*, was an ironic comment on its far from Olympian status. The thinkers whose works they reflected upon included Henri Poincaré, Ernst Mach and David Hume, all of whom significantly influenced Einstein's own subsequent ideas and beliefs.

A few years later in 1905, Einstein published four major papers: on the photoelectric effect, on the Brownian motion, his special theory of relativity and the equivalence of mass and energy. These papers led to that year being called an *annus mirabilis* for physics, akin to 1666, the year in which Isaac Newton experienced his greatest epiphanies.

In the following treatise, the first of the *Annus mirabilis* papers, he deduces that electromagnetic radiation itself consists of "particles" of energy, hv. Einstein arrives at this conclusion by using a simple theoretical argument comparing the change in entropy (disorder) of an ideal gas caused by an isothermal change in volume with the change in entropy of an equivalent volume change for electromagnetic radiation in accordance with Wien's or Planck's radiation law. This derivation and comparison makes no reference to substances and oscillators. At the end of the paper, Einstein concludes that if electromagnetic radiation is quantized, the absorption processes are therefore quantized too, providing an elegant explanation of the threshold energies and the intensity dependence of the photoelectric effect. He goes on to predict that the kinetic energy of the electrons emitted in the photoelectric effect increases with light frequency v proportional to $hv - P$, where P is "the amount of work that the electron must produce on leaving the body." Einstein would later receive the 1921 Nobel Prize in Physics for his investigations of light quanta.

Einstein, close to the time of publication

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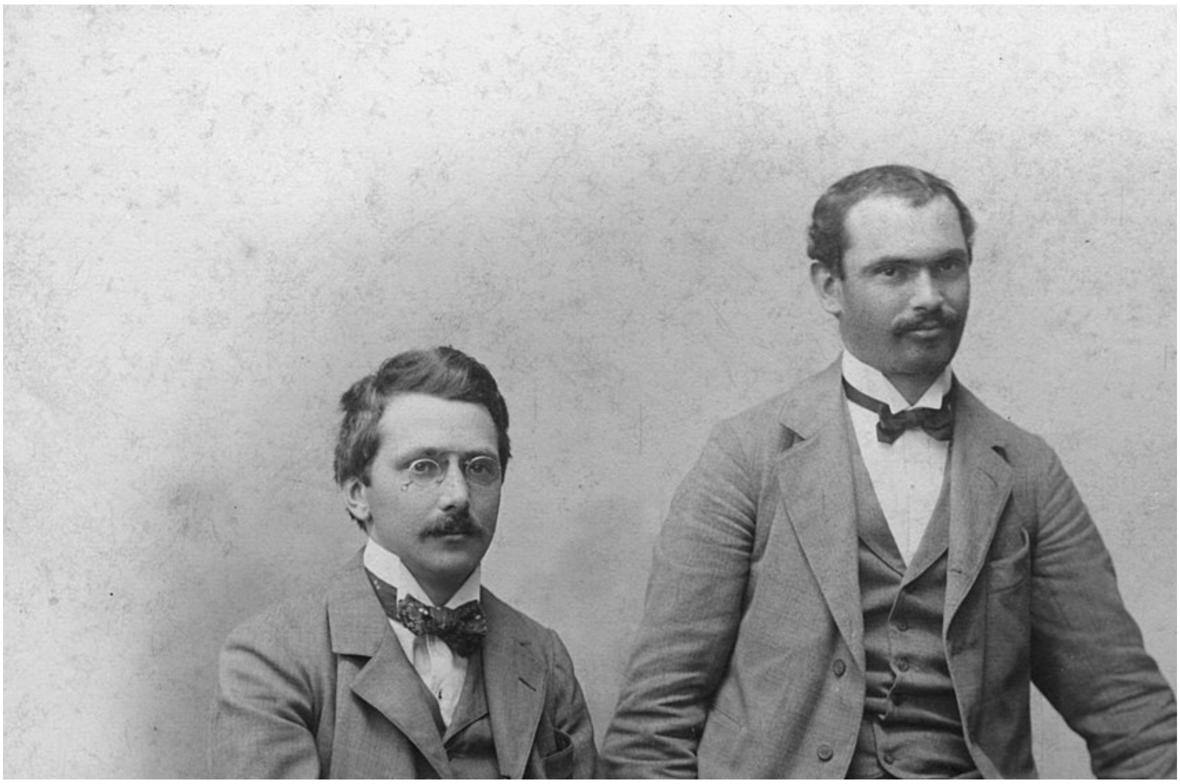

The Olympia Academy founders: Conrad Habicht, Maurice Solovine and Einstein

On a Heuristic Point of View about the Creation and Conversion of Light

MAXWELL'S THEORY OF electromagnetic processes in so-called empty space differs in a profound, essential way from the current theoretical models of gases and other matter. On the one hand, we consider the state of a material body to be determined completely by the positions and velocities of a finite number of atoms and electrons, albeit a very large number. By contrast, the electromagnetic state of a region of space is described by continuous functions and, hence, cannot be determined exactly by any finite number of variables. Thus, according to Maxwell's theory, the energy of purely electromagnetic phenomena (such as light) should be represented by a continuous function of space. By contrast, the energy of a material body should be represented by a discrete sum over the atoms and electrons; hence, the energy of a material body cannot be divided into arbitrarily many, arbitrarily small components. However, according to Maxwell's theory (or, indeed, any wave theory), the energy of a light wave emitted from a point source is distributed continuously over an ever larger volume.

The wave theory of light with its continuous spatial functions has proven to be an excellent model of purely optical phenomena and presumably will never be replaced by another theory. Nevertheless, we should consider that optical experiments observe only time-averaged values, rather than instantaneous values. Hence, despite the perfect agreement of Maxwell's theory with experiment, the use of continuous spatial functions to describe light may lead to contradictions with experiments, especially when applied to the generation and transformation of light.

In particular, black body radiation, photoluminescence, generation of cathode rays from ultraviolet light and other phenomena associated with the generation and transformation of light seem better modeled by assuming that the energy of light is distributed discontinuously in space. According to this picture, the energy of a light wave emitted from a point source is *not* spread continuously over ever larger volumes, but consists of a finite number of energy quanta that are spatially localized at points of space, move without dividing and are absorbed or generated only as a whole.

Subsequently, I wish to explain the reasoning and supporting evidence that led me to this picture of light, in the hope that some researchers may find it useful for their experiments.

A Certain Problem Concerning the Theory of "Black Body Radiation".

WE BEGIN BY applying Maxwell's theory of light and electrons to the following situation. Let there be a cavity with perfectly reflecting walls, filled with a number of freely moving electrons and gas molecules that interact via conservative forces whenever they come close, i.e. those collide with each other just as gas molecules in the kinetic theory of gases.[1]

In addition, let there be a number of electrons bound to spatially well-separated points by restoring forces that increase linearly with separation. These electrons also interact with the free molecules and electrons by conservative potentials when they approach very closely. We denote these electrons, which are bound at points of space, as "resonators", since they absorb and emit electromagnetic waves of a particular period.

According to the present theory of the generation of light, the radiation in the cavity must be identical to black body radiation (which may be found by assuming Maxwell's theory and dynamic equilibrium), at least if one assumes that resonators exist for every frequency under consideration.

Initially, let us neglect the radiation absorbed and emitted by the resonators and focus instead on the requirement of thermal equilibrium and its implications for the interaction (collisions) between molecules and electrons. According to the kinetic theory of gases, dynamic equilibrium requires that the average kinetic energy of a resonator equal the average kinetic energy of a freely moving gas molecule. Decomposing the motion of a resonator electron into three mutually perpendicular oscillations, we find that the average energy of such a linear oscillation is

where R is the absolute gas constant, N is the number of "real molecules" in a gram equivalent and T is the absolute temperature. Because of the time averages of the kinetic and potential energy, the energy is ⅔ as large as the kinetic energy of a single free gas molecule. Even if something (such as radiative processes) causes the time-averaged energy of a resonator to deviate from the value , collisions with the free electrons and gas molecules will return its average energy to by absorbing or releasing energy. Hence, in this situation, dynamic equilibrium can only exist when every resonator has an average energy .

We apply a similar consideration now to the interaction between the resonators and the ambient radiation within the cavity. For this case, Planck has derived the necessary condition for dynamic equilibrium [2]; treating the radiation as a completely random process.[3]

He found:

Here, is the average energy of a resonator of eigenfrequency v (per oscillatory component), L is the speed of light, v is the frequency, and $\rho_v dv$ is the energy density of the cavity radiation of frequency between v and $v + dv$.

If the net radiative energy of frequency v is not to continually increase or decrease, the following equality must hold

or, equivalently,

This condition for dynamic equilibrium not only lacks agreement with experiment, it also eliminates any possibility for equilibrium between matter and aether. The wider the range of frequencies of the resonators is chosen the bigger the radiation energy in the space becomes, and in the limit we obtain:

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End of Sample