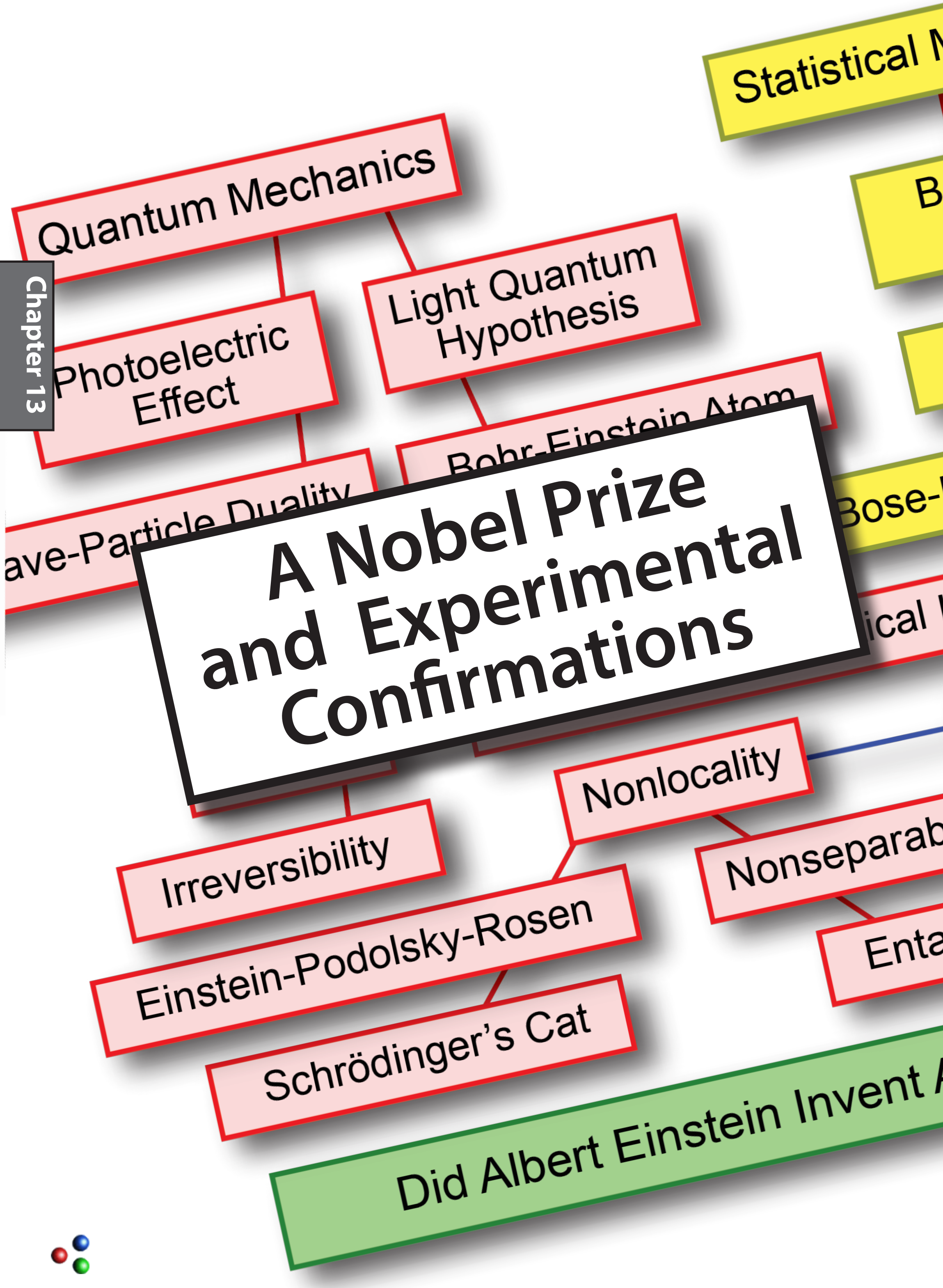
A Nobel Prize and Experimental Confirmations



A Nobel Prize and Two Experimental Confirmations

In 1910 Robert A. Millikan established himself as one of the world's leading experimentalists with his "oil-drop" experiment that measured the elementary charge on the electron. The charge-to-mass ratio had been predicted by J.J.Thomson, the discoverer of the electron, so Millikan's work now provided both the charge and the mass independently.

Like most physicists, theoreticians and experimentalists, Millikan doubted Einstein's light quantum hypothesis, and he set out to build the cleanest possible surface in a vacuum that could test Einstein's prediction that the relation between light frequency and the energy of an ejected electron is linear. The graph should be a straight line (see p.55).

While admitting that Einstein's photoelectric equation "represents very accurately the behavior," Millikan wrote that it "cannot in my judgement be looked upon as resting upon any sort of satisfactory theoretical foundation." When Einstein learned of the experimental confirmation of his prediction, along with the denial of his theory, the first World War had begun and all his energies were devoted to his general theory of relativity.

At this time, Einstein felt very much alone in believing the reality (his emphasis) of light quanta:

> I do not doubt anymore the *reality* of radiation quanta, although I still stand quite alone in this conviction.[1]

It would be many more years before most of the physics community would accept Einstein's radical hypothesis, this despite two more dramatic confirmations of Einstein's predictions.

The first experimental confirmation was not for Einstein's work in quantum mechanics but for his 1916 theory of general . Arthur Stanley Eddington's eclipse expedition of 1919 made Einstein world-famous overnight. Eddington measured the angle of deflection of light from a distant star as it passed close to the surface of the darkened sun, its path curved by the sun's gravity.

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[1] Letter to M. Besso, quoted by Pais, 1982 p.411

Einstein's 1905 theory of special relativity had of course made him well-known among physicists and he had been frequently nominated for a Nobel Prize. But some members of the Nobel committee found Einstein's relativity theories too controversial and in 1920 they awarded him the prize for his predictions of the photoelectric effect that had been confirmed by Millikan.

Like Millikan and many others, those awarding the prize did not in any way recognize Einstein's theoretical reasoning behind his 1905 prediction, that a discrete and localized quantum of light had been completely absorbed by a single electron.

The confirmation that light has such particle properties came in 1923 when Arthur Holly Compton confirmed Einstein's 1916 prediction that light has the same property of momentum as a material particle. Compton showed that when light and matter interact, their collision can be described as two material particles colliding, with one scattering the direction of the other, and with the conservation of energy and momentum.

Compton measured the scattering angle after the collision between light and an electron and it agreed perfectly with Einstein's prediction that the light quantum carries momentum $p = h\nu/c$.

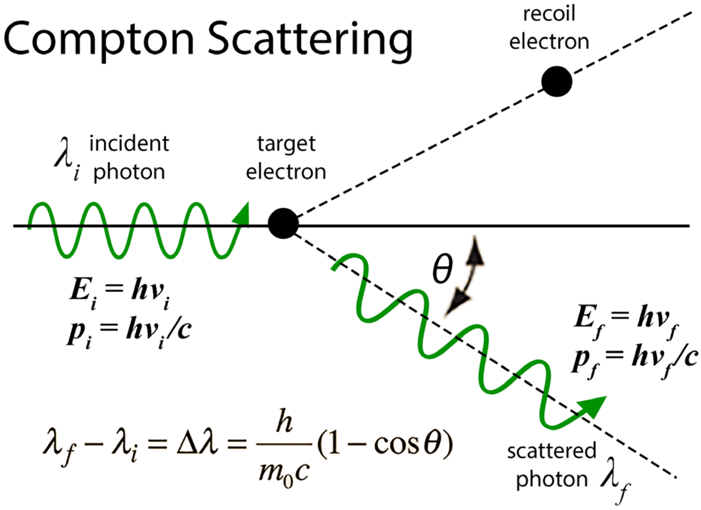

Figure 13-10. The angular measurement by Compton when a "particle" of light collides with an electron and is scattered into a new direction.

Compton scattering is "inelastic," because the energy $h\nu_i$ (or hc/λ_i) of the incident photon is different from that of the scattered photon $h\nu_f$ (or hc/λ_f). The lost energy is in the recoil electron.

The initial horizontal momentum is divided between the recoil electron and the scattered photon. The vertical momenta of the recoil electron and scattered photon are equal and opposite.

Compton's experiments confirmed the relation

$$\lambda_f - \lambda_i = (h/m_0c) (1 - \cos\theta).$$

Depending on the angle θ, the wavelength shift $\lambda_f - \lambda_i$ varies from 0 to twice h/m_0c, which is called the Compton wavelength.

This "Compton Effect" provided real support for the wave-particle duality of radiation and matter, which as we have seen Einstein had proposed as early as 1909.

Like Millikan, Compton himself initially denied that his experiment supported Einstein's idea of light quanta. Confirmations of Einstein's extraordinary predictions did not at first convince most of his colleagues of his revolutionary theoretical insights!

WERNER HEISENBERG used the Compton Effect in his gamma-ray microscope as an explanation for his uncertainty principle. Although Heisenberg denied the existence of particle paths,[2] we can visualize them using conservation principles for energy and momentum, as Einstein's "objective reality" always suggested.

WOLFGANG PAULI objected to Compton's analysis. A "free" electron cannot scatter a photon, he argued. A proper analysis, confirmed by Einstein and PAUL EHRENFEST, is that scattering should be a two-step process, the absorption of a photon of energy $h\nu_i$ followed by the emission of a scattered photon $h\nu_f$, where the momentum of the photon $h\nu_f/c$ balances the momentum of the recoil electron m_0v.

Compton was awarded the Nobel Prize in Physics in 1927 for the "Compton Effect," the year that Heisenberg discovered quantum indeterminacy, by which time most physicists were accepting Einstein's light quanta, since 1924 being called photons.

A year after Compton's work, LOUIS DE BROGLIE would in his 1924 thesis propose that by symmetry, matter should show wave properties just like those of light, an idea that de Broglie said had been suggested to him by reading Einstein.

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[2] See chapter 21