Robert H Dicke – Physicist Extraordinaire

Robert Dicke (1916–1997) was a remarkable physicist of the last century. His name is not that well known, but this lack of fame is belied by his contributions to experimental and theoretical physics, as the following tribute will show.

Dicke started his college education at the University of Rochester intending to major in engineering. He credits Lee A DuBridge with attracting him to physics and Frederic Seitz at Rochester and E U Compton at Princeton University for facilitating his transfer to Princeton as a Junior. After finishing his undergraduate education, he returned to the University of Rochester for graduate work in nuclear physics. He completed research for his PhD degree in the spring of 1941. His topic, which he himself had selected, was one of the first experimental studies of inelastic scattering of protons. He recalls that “Professor DuBridge offered me a position as Instructor in the Department for the following fall. I was happy to accept but didn’t have a chance to serve. War rumblings were growing louder and Professor DuBridge had left to establish the Radiation Laboratory at MIT to develop microwave radar. A few months later he asked me to join the Laboratory as soon as I could get my thesis finished. I arrived at MIT in September of 1941.”

While at the Radiation Laboratory (known fondly as Radlab), Dicke developed his microwave radiometer, which he used to do some ‘pure science’ on the side such as measuring the surface temperature of the moon and showing that the space between the stars could not be warmer than 20K. The latter result simply means that he detected no signal, and therefore could say that it must be weaker than what would be radiated by a blackbody at 20K, at centimetre wavelengths. He also introduced two ingenious innovations. The first was the magic-tee microwave junction (akin to a half-silvered beam splitter in optics), now an integral part of radio telescopes. The second was the idea of switching or on-off modulation to extract signals in the presence of low-frequency noise (also called drift). This works because the modulated signal (usually at a higher frequency) is easily separated from the noise (which is at a lower frequency). This idea is now exploited in the ubiquitous lock-in amplifier discussed further below. Many of Dicke’s contributions appear in the book titled *Principles of Microwave Circuits* (by C G Montgomery, R H Dicke and E M Purcell) published as part of the MIT Radiation Laboratory Series.

After the war, he returned to the Department of Physics at Princeton University. He spent the next decade on fundamental studies on the quantum mechanical interaction of radiation and matter (see the article on atomic physics by VN for details). In 1960, along with his former student, James P Wittke, he wrote a book titled *Introduction to Quantum Mechanics*, which remains a standard textbook in the field.

After a sabbatical year at Harvard in 1954–55, Dicke turned his attention to cosmology and gravitation. He was inspired by Dirac’s large numbers hypothesis and Mach’s principle to come up with the Brans–Dicke theory, a modification to Einstein's General Relativity (GR) as a theory of gravitation (see the article by Narlikar for details). More than anything else, it made Einstein's theory testable by providing an alternative. His ideas on why the Brans–Dicke theory is superior are presented in his *American Journal of Physics* article, reproduced in Classics.

Dicke was involved in several precision tests of gravity. The most famous is his version of the Eötvös experiment to test the equivalence principle, which states that the gravitational mass of a body is exactly equal to its inertial mass. The equivalence principle is one of the cornerstones of general relativity theory. Dicke's modern experiment was more than 100 times better than the original. He was also involved in measuring the oblateness of the Sun, an experiment designed to test the hypothesis that the classic evidence for GR based on the perihelion precession of Mercury may be compromised by the departure from a spherical mass distribution in the Sun. The results came out in support of GR, but Dicke was able to push the accuracy of ground-based observations to their limit. Dicke and his students were also involved in other precision measurements of gravity. For example, (i) They found that the gravitational redshift of the solar spectrum was 1.05 ± 0.05 times the predicted value, (ii) they obtained an improvement of the Kennedy–Thorndike bound on the variation of an oscillator frequency with velocity relative to a preferred frame, and (iii) they devised an experiment to look for spatial variation of the gravitational interaction (Nordtvedt effect) using corner-cube reflectors to precisely measure satellite distances. Dicke's role in the discovery of the cosmic microwave background, a relic of the big bang, is legendary and is discussed below.

Dicke was probably an engineer at heart, as evidenced by the over 50 patents he held, but was proud to point out that his father, a railway engineer, had even more! He received many awards and prizes, including the National Medal of Science in 1971, one of the highest honors in the United States. But he is perhaps best known for missing Nobel Prizes on numerous occasions.

Missed Nobels

Dicke developed his ideas of microwave modulation into the lock-in amplifier (also known as phase-sensitive detector). This is now an indispensable tool in science and engineering laboratories. The basic idea, as explained earlier, is similar to that of a radio receiver – the signal is modulated on to a carrier wave, and then demodulated to get the in-phase and out-of-phase quadratures. He started a company, Princeton Applied Research or PAR, to market lock-in amplifiers. Many of us feel that Dicke deserved a Nobel Prize just for inventing such a ubiquitous experimental tool. But there are several other instances where circumstances conspired to deny him his due, as exemplified in the following list.

1. ***Dicke Narrowing and the Mossbauer Effect*****:** In a seminal paper on the effect of collisions on the line width of spontaneous emission, Dicke showed that if the effect of collisions was to confine the particle to a region smaller than the wavelength, the emission from the particle would be *recoilless*. The reader is referred to the article by one of us (VN) in this issue for further details, but the narrowing that Dicke is predicting is analogous to the Mössbauer effect seen for gamma rays in a crystal. Dicke was thinking of atomic transitions but could have mentioned that the regime of confinement below a wavelength could be achieved more easily for nuclear transitions. Mössbauer saw this recoilless line a few years later and won the Nobel Prize for it.

2. ***The Cosmic Microwave Background Radiation (CMBR)*****:** The CMBR is the remnant of radiation left over from the big bang. As mentioned earlier, Dicke had already set a limit of 20K on the CMBR temperature while he was at the Radiation Laboratory. After he was back at Princeton, in the early 1960's he did an estimate of this temperature, and along with a few colleagues set up a Dicke radiometer to look for this radiation. He was unfortunately scooped because, just a few miles from Princeton, Penzias and Wilson at the AT&T Bell Labs, had detected 'excess antenna temperature' (i.e., a signal over and above what they could account for) at a wavelength of 7 cm. They were not even looking for an early hot phase of the universe but just understanding the noise in an antenna (of course a Dicke radiometer) meant for different purposes. The theoretical interpretation was provided by Dicke and his colleague Peebles, but the Nobel Prize (rightly) went to Penzias and Wilson for detecting the CMBR. Perhaps it is some compensation that one of his younger experimental colleagues, David Wilkinson, went on to be a key person in a satellite experiment called MAP (which was later named after him and became WMAP). This has given some of the most accurate measurements of the CMBR with far-reaching consequences for cosmology – an age of the universe of 13.7 billion years. The precision would have been laughable before WMAP!

3. ***Aperture Synthesis*****:** As a distinguished physicist, Dicke served on several committees, and in one of them, he wrote a small note on how signals from different radio telescopes could be combined to yield more detailed information than what could be obtained from one telescope alone. This was never published, but he had independently arrived at the basic principle used by virtually all the great radio telescopes today, called aperture synthesis, which won the Nobel Prize for Ryle in Cambridge.

4. ***Other Precision Measurements*****:** Dicke was involved in several other precision measurements which resulted in Nobel Prizes (for others!). After returning to Princeton, he started to measure the fine structure of the n=2 level of hydrogen, but on learning that Willis Lamb (Nobel 1955) was already working hard on that problem with the resources of the Columbia Radiation Laboratory, he turned to other challenges. He refused to assume that the Landég-factor of the free electron could not be measured in an atomic beam, and began to generate free electrons by photoionization of sodium atoms with circularly polarized light. Unaware of the work of Alfred Kastler (Nobel 1966) in Paris, he carried out one of the first optical pumping experiments on a beam of sodium atoms.

In many ways, Dicke was a radical. Perhaps it was the time in which he grew up, with a great depression and a world war. He was independent and ingenious, partly due to his childhood exposure to chemistry sets and radio sets. He was not afraid to suggest alternatives to a widely-accepted theory such as general relativity. But he also worked to test his radical ideas – it was not just radical posturing. He taught us how to do precise tests of gravity. Most of his results may have come out in support of GR, but this did not deter him.

Robert Dicke holds a special place in the history of twentieth century physics for the sheer range of his talents and contributions.

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