Interlude

ACOUSTICS IN THE INTERNATIONAL YEAR OF PHYSICS

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As readers may or may not know, the year 2005 has been designated by the United Nations as the International Year of Physics. Although the present issue of *Acoustics Australia* is nominally that for December 2004, most of you will not be reading these words until January 2005, so it is appropriate to reflect briefly upon the role of acoustics in the history of physics.

First, however, let me remind you of why there is something special about the year 2005 in relation to physics. It all relates to someone who is today regarded as probably the most famous physicist of all time, Albert Einstein. In 1905 he was working as a patent examiner in the Patents Office in Zurich, Switzerland, a position that he apparently enjoyed, although he was ultimately to become a University Professor. In the spare time allowed from his work he carried out experiments and devised theories in physics, and in 1905 he published three papers that revolutionised the subject.

The first, and least quoted of these, was an explanation of Brownian motion, the jittering behaviour of tiny particles suspended in liquid when they are observed with a microscope. This he interpreted in terms of the random impact of molecules in the surrounding liquid, and from this he devised a theory to explain diffusion at a molecular level.

The second was his explanation of the photoelectric effect, in which electrons are emitted from a solid under the influence of light, for which he was awarded the Nobel Prize in 1921. Why was this so important? Well, it showed that light, which was well known at the time to be an electromagnetic wave, behaved also as a stream of particles, much as Newton had thought two hundred years before. Einstein thus shed new light on Planck's equation $E=h\nu$ for the energy E of one of these particles, later called a photon, where h is Planck's constant and ν is the frequency of the light involved. This work paved the way for the later development of modern quantum mechanics by Schrödinger, Heisenberg and Bohr.

The third paper put forward Einstein's most celebrated work, the theory of Special Relativity, and introduced the equation $E=mc^2$, which is certainly the most famous equation in modern physics. This equation relates the energy E contained in a particle to its mass m and the speed of light c. It shows ultimately that, by sacrificing a very small amount of mass, an immense amount of energy can be released. This led in due course to an understanding of the Sun's energy and to the development of nuclear reactors and the atomic bomb.

So what does acoustics have to do with all of this, apart from the fact that Einstein played the violin? At first sight one might be inclined to say "Nothing!" But perhaps we have to look back much further in the history of physics to find the connection, and this is what I will try to do here. I know of three excellent books on the history of acoustics, by R. Bruce Lindsay [1], Frederick V. Hunt [2], and Robert T. Beyer [3] respectively. I have consulted these frequently in writing this short piece and I leave you to check these for further details on what I have written. They will well repay your attention.

IN THE BEGINNING ...

Physics as we know it today can probably be regarded as beginning with the Greek philosopher Pythagoras in about 600 BC. Certainly there were many well-developed technological activities such as metallurgy and architecture before that time, but Pythagoras was one of the first to attempt to quantify behaviour in numerical terms. He was particularly fascinated with small prime numbers such as 2 and 3, and felt that much of the universe could be explained in numerical terms. According to legend, one reason for this fascination was his observation that musical intervals such as the octave and the fifth corresponded to dividing the length of a string in simple ratios such as 2:1 (for the octave) and 3:2 (for the fifth). These two primes remained the basis of musical tunings for nearly a thousand years, and it was not until the time of the Muslim philosopher Al Farabi or Alpharabius (ca. 870–950AD) that the third prime 5 was introduced and made the musical major and minor thirds (5:4 and 6:5) concordant. These intervals were regarded as discords in Pythagorean tunings, since their ratios were 81:64 and 32:27 respectively and thus far from simple. Modern ears, of course, have become tolerant of discords because of the use of equal temperament, in which no intervals except the octave have a simple frequency ratio and everything is based upon $2^{1/12}$. Musical acoustics was not just concerned with tunings, however, and as early as the 13th Century Safi al-Din produced a good qualitative description of resonance in the tubes of wind instruments in terms of the reflection of pulses of air.

Music, in ancient times, was also taken to be the basis of astronomy, or at least of the arrangement of the planets in the solar system. The "Music of the Spheres" tended to dominate ancient astronomical thinking and, while it proved to be a false analogy, it did at least serve to bring some sort of order into what was otherwise a completely inexplicable system.

Music, the underlying theme of acoustics, was also close to the basis of medieval education, which was traditionally divided into two parts. The more basic disciplines Grammar, Rhetoric and Logic constituted the *trivium* (from which is derived our word "trivial"), for without knowledge of these no-one could express themselves effectively and be considered educated. Above the trivium came the *quadrivium*, consisting of Arithmetic, Geometry, Music and Astronomy, for these four subjects were those upon which something intellectually useful might be said.

One of the most widely known early observations in the science of acoustics and vibration was that of Galileo (1564–1642), who introduced the modern concept of frequency and observed, during a long and boring religious ceremony, that the period of a pendulum is independent of its amplitude. Galileo is, of course, best known for his astronomical theories, but in the present context it is relevant to note that he also "had a modest skill on the lute". I return to this observation later. Another important contributor to acoustical knowledge at about this time was Marin Mersenne (1588–1648), who wrote several books on the subject and was also a well-known composer whose works are still heard today. Among many other things, he made semi-quantitative measurements of the speed of sound, arriving at the value of 448 m/s, which is pretty good considering the measurement apparatus available at the time. Isaac Newton returned to this problem from a theoretical perspective about a hundred years later.

Architectural acoustics, of course, also has a very long history, albeit of a rather qualitative but practical kind. Seneca (4BC–65AD) posed questions about the effect of absorbent straw placed on the floor where an orchestra is playing, while Vitruvius (ca. 25BC) at about the same time raised questions about reverberation. Without a doubt, however, the amphitheatres built in Roman times and the cathedrals built nearly a thousand years later do have very impressive acoustical properties. By the 17th century, architects had a good understanding of sound propagation and reflection, as indicated by the architectural drawings of Athanasius Kircher in about 1650.

MODERN TIMES

Acoustical knowledge developed steadily from the time of Newton (1642–1727) in a prelude to modern times. Among the famous mathematicians and physicists who published books and papers on acoustics can be numbered Euler, Lagrange, Poisson, Laplace, Wheatstone, Faraday and Ohm. Details of some of their contributions can be found in the compilation by R.B. Lindsay [1]. All of them, of course, also contributed immensely to other branches of mathematics and physics.

Modern times in acoustics, however, begin with Hermann von Helmholtz (1821–1894) and John William Strutt (1842–1919), later to be Lord Rayleigh. The immensely influential books that they published on the subject [4,5] are still consulted today. Both were notable scientists – Rayleigh as Professor of Physics at Cambridge and Helmholtz as Professor of Physiology in a succession of German universities, and then the first Director of what is now the PTB (the Physikalisch Technische Bundesanstalt), the premier government physics laboratory of Germany. Rayleigh, in particular, set down mathematical versions of the theory of acoustics which, in that they described waves of many types and included dispersion phenomena and variational principles, later provided much of the mathematical basis of quantum mechanics (though he did not, of course, foresee the Schrödinger equation!).

A further notable advance in acoustics took place in the late 19th century with the development of mechanical and then electronic methods for recording, analysing, and distributing sound. It is interesting to note in this connection that Edison had a strong interest in acoustics and was made the first Honorary Fellow of the Acoustical Society of America in 1928, less than a year after its foundation. No other Honorary Fellow was appointed for another ten years.

As in most branches of science, the twentieth century saw huge advances in physics generally, and these tend to overshadow the advances made in acoustics. But think where we would be without those advances. No stereophonic sound, or even high quality sound reproduction at all. No music CDs or even LPs. No broadcast concerts on radio or TV. No electronic musical instruments. No ultrasound medical scanning. Certainly life would still go on, but it would be much less rich in sensory experience.

MUSIC AND LIFE

Finally, let me comment briefly upon the relationship between music and the intellectual lives of some of the great physicists, and even of the ordinary physicists of today. I have already mentioned that Mersenne played the lute and Einstein played the violin. How many other famous scientists were also competent performing musicians I do not know, but an observation of the connection between physics and music in contemporary society is illuminating. I have myself played in perhaps half a dozen amateur orchestras in America and Australia, and I have recently made a practice of discovering the educational and occupational backgrounds of the more competent players in these groups. Omitting those few who are retired professional musicians, I find that, somewhat surprisingly, the overwhelming majority of these players have a background in mathematics, physics or engineering and a smaller number in other branches of science; very few have a background in the humanities or social sciences. It seems that competence in the actual performance of music is closely related to ability in the physical sciences, while those whose interest is in the humanities are generally content to write about and discuss the subject without having much practical ability themselves. I put this hypothesis forward as a fruitful theme for a possible PhD thesis in psychology!

Let me return then to restate my original theme. I believe that there has always been a close link between acoustics, particularly in its most refined form as music, and deep and original thinking in mathematics and the physical sciences. The Australian Institute of Physics is holding a special Congress in Canberra from January 31 to February 4, 2005, and our Society is organising two special sessions on Acoustics and Music. Let us join in celebrating this International Year of Physics in the knowledge that this also makes it the International Year of Acoustics.

REFERENCES

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