Reflections

That One Year !

1905 must stand out as the year of wonders in Einsteins life, *annus mirabilis*. The only parallel that comes to mind is Newton's two plague years 1666–1667, spent in the peace and quiet of his native Woolsthorpe. By Newton's own account, the seeds of all his great mathematical and physical discoveries – relating to calculus, universal gravitation and optics – were sown in that period.

Let us take a brief look at four scientific papers which Einstein submitted to the prestigious journal, *Annalen der Physik*, in the months of March, May, June, and September 1905. The March paper has the title 'On a heuristic point of view concerning the generation and conversion of light'. Its subject was nothing less than the true nature of radiation, today, every schoolboy has heard of the word 'quantum' and the name of Max Planck who took the first step toward this idea. But it was really Einstein who first clearly stated that radiation energy itself came in these fundamental units, which we call photons today. Einstein went further and used his light quantum hypothesis to explain one of the leading puzzles in physics at that time. This was the photoelectric effect, in which electrons are emitted from a metal on which light falls. As such, there was no surprise in the transfer of energy from a beam of radiation to electrons. But the experiments showed that the frequency of light played a vital role – if it was below a certain value, there was no emission even for a strong beam, while if it was above the critical value, even a weak beam could cause emission of electrons. Once it was accepted that the energy came in quanta and a single unit was responsible for emission of a single electron, this mystery was solved. But the price was that nearly half a century of physics based on the notion of electromagnetic radiation in the form of continuous waves had to be reviewed. Einstein was fully aware of it, hence the cautious words in the title 'heuristic point of view' (meaning point of view which may be useful in making further progress). It needed many more contributions – Einstein himself in 1917, Bose in 1924, and Dirac in 1927, before the picture was complete. But the first step had been taken in Einstein's March 1905 paper. It won him the Nobel Prize for Physics in 1921.

By May 11th, Einstein had completed and sent off another fundamental piece of work. This time the title was *'On the motion required by the molecular kinetic theory of heat of particles suspended in fluids at rest.'* This was on the subject of colloids (of which milk is an example) in which particles big enough to be seen individually are suspended in a fluid. The motivation for this study was another long standing mystery, the phenomenon of Brownian motion, originally noted by the botanist Brown for pollen grains in water. Einstein developed a full theory of the diffusion (spreading out from the point of origin) of such particles, their mobility under the action of external forces, and indeed deduced the value of the Avogadro number (e.g., the number of hydrogen atoms in a gram) in fair agreement with what he had himself

derived from the study of radiation. He proposed precise tests of his theory which were later carried out by J Perrin and which removed all doubts of the reality of molecules and their thermal motion.

Pretty good going for a twenty seven year old patent clerk working essentially alone and far away from any of the great scientific centres of the day? Well, more was to come to the *Annalen der Physik* in the month of June. This was a paper entitled 'On the electrodynamics of moving bodies'. This paper created the special theory of relativity, destroyed the concepts of absolute time and simultaneity, introduced the notions of length contraction and time dilatation. Problems which the best minds of the day, Lorentz and Poincaré, were struggling with for a decade were solved by this rank newcomer to the scene. The other authors were close to a mathematical solution but only Einstein had the courage and clear vision to accept the physical implications wholesale.

Of course, the short times between papers on very different subjects is misleading. Einstein had been thinking about all these problems for many years. But there is no doubt that many things must have crystallised in his mind in these magic six months. Perhaps we can therefore forgive him for missing something else for a whole three months. It emerged in September, as a shorter paper, also in the area of special relativity. Its title asked the question 'Does the inertia of a body depend on its energy content?' The answer was given in the form of an equation, $m = E/c^2$. Slightly rearranged, it becomes the equivalence and interconvertibility of mass and energy $E = mc^2$ – one of the most famous physical concepts of our times. And also one of the most infamous, since it formed the basis for measuring the energy content of nuclei, for predicting which reactions between them would lead to a large energy release, viz, fission of heavy nuclei and fusion of light ones. In other words, the September 1905 paper was the starting point on the long road that led to the uranium and hydrogen bombs.

Looking back, such a burst of creativity from a single mind in a single year is probably unparalled in our times. The 1905 volume of *Annalen der Physik* stands to tell us that all this really happened.

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Why does this magnificent applied science, which saves work and makes life easier, bring us so little happiness? The simple answer runs: Because we have not yet learned to make sensible use of it.

Albert Einstein