My New Scientist

What's logic got to do with it? - Some of the greatest flashes of scientific inspiration were sparked by utterly illogical thinking. Marcus Chown celebrates three triumphs of muddled reason

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POPULAR belief has it that science is the preserve of logical Mr Spocks. A great scientific discovery must surely spring from a series of logical steps, each taken coolly and calmly, in the rational order. But take some time to leaf through the pages of history and you will find the surprising truth. Some of the greatest discoveries in science were only made because logic fell by the wayside and some mysterious intuition came into play.

Fortune has occasionally smiled on those who abandon all reason, and what better year to celebrate them than 1996? For it is exactly 100 years since the French chemist Henri Becquerel was ledby an unfounded belief that certain rocks emit X-rays and some inexplicable experiments in his laboratory in Paristo one of the most monumental discoveries in history: that of radioactivity.

Like his father and grandfather before him, Becquerel had an obsessive interest in minerals that glowed, or fluoresced, after exposure to sunlight. He was trying to get to the bottom of this in January 1896 when he heard the sensational news of the discovery of X-rays by the German physicist Wilhelm Röntgen. Becquerel was struck by the thought that the fluorescent minerals he had been studying might react to sunlight not only by glowing with visible light, but also by emitting invisible X-rays.

He set out to test this by wrapping a photographic plate in dark paper, so that light could not get at it, and placing it on a sunlit windowsill. On top of the plate he arranged various fluorescent minerals. He reasoned that if sunlight triggered a mineral to produce X-rays, in addition to visible light, then the X-rays should easily penetrate the paper and blacken the photographic plate.

Flash of genius

To Becquerel's disappointment, a whole series of fluorescent minerals failed to blacken the wrapped plate. Nonetheless, he persisted for weeks with various samples and got round to the uranium salt potassium uranyl disulphate. Here he came up trumps. On 24 February 1896, he reported to the French Academy of Sciences that this uranium mineral emitted rays that penetrated paper and blackened a photographic plate.

Without firm evidence that the mystery rays were actually X-rays, Becquerel set about finding their properties. He began another windowsill experiment in which he placed a small copper cross between the sample and the wrapped photographic plate. If the rays travelled in straight lines, as Röntgen's X-rays did, then the developed plate would show the shadowed outline of the cross.

On 26 February, much to Becquerel's frustration, the Parisian sky was completely overcast and he was unable to carry out his experiment. Instead, he took the entire apparatusuranium salt, wrapped photographic plate and copper crossand placed it in the drawer of a cabinet. There it remained, in total darkness, for several days during which time the Sun made only fleeting appearances in the wintry sky above the city. Eventually Becquerel's impatience got the better of him. On 1 March he removed his apparatus from the dark drawer and developed the photographic plate.

Why he did this is a fascinating question worthy of an article in itself. Becquerel was studying an effect which he believed was triggered by sunlight, yet he developed the plate knowing full well that it had languished for days in complete darkness. Perhaps he had a hunch. Perhaps it was a sixth sensethe flash of unpredictable genius that separates the few scientists who make great discoveries from the many who do not.

Whatever his motivation, Becquerel developed the plate. And what he saw left him open-mouthed in disbelief. Shining out in brilliant white against the black background was the image of the copper cross. The rays that he had reported to the Academy of Sciences barely a week before were still emitted, in the dark, with undiminished intensity.

There was only one explanation. The rays coming from the uranium mineral were not triggered by sunlight or by any other obvious external agent. They had nothing to do with fluorescence. Instead, they were intrinsic to the uranium salt. What Becquerel had discovered was an entirely new phenomenonone which Marie Curie would two years later christen "radioactivity".

Bottomless energy

The characteristic of radioactivity that Becquerel found most astonishing was its persistence. Becquerel could detect no weakening in the "uranium rays", as he called them. They poured out in an unending stream, week after week, month after month, drawing on an apparently bottomless source of energy. It was the first indication that inside ordinary matter is a mind-boggling energy supply. For his epoch-making discovery, Becquerel shared the 1903 Nobel Prize for Physics with Marie and Pierre Curie.

Becquerel is not alone in being led to a major scientific discovery by a faulty chain of logic. Take the case of William Harvey, the 17th-century English physician who discovered the circulation of the blood. Harvey, who treated James I and Charles I, saw the human body as a microcosm of the Universe. He believed that the same "absolute ruler" governed both, and so he looked to the heavens for insights into the workings of the body.

And so, bizarre as it may sound, the orbits of the planets inspired Harvey's triumphant discovery of the circulation of the blood. "I began to think whether there might be a motion of the blood as if it were in a circle," wrote Harvey. He then pondered the discovery made a century earlier by Nicolaus Copernicus that the planets did not circle the Earth but instead orbited the Sun, the life-giving source of energy in the Solar System. The energy source for the circulation of the blood then seemed clear to Harveyit must be a central organ, most likely the heart. "The heart," he wrote, "is the Sun of the microcosm."

Harvey went on to test his ideas on circulation by dissection and experiment. He demonstrated, for instance, that blood flows through arteries, veins and heart valves in one direction only. He showed that the heart is a muscular pump that expels blood by contracting, and that blood returns to the heart through the veins. Yet Harvey made his great discoveryand in the process founded the science of modern physiologyon the basis of a fallacious theory that there was an intimate connection between blood and the planets.

In common with physiology, the modern theory of the origins of the Universethe big banghad some rather dubious early days. The big bang theory was first suggested by Soviet-American physicist George Gamow. In the late 1930s, Gamow set out to explain where the chemical elements had come from. What was the origin of the iron in our blood, the calcium in our bones, and the oxygen that fills our lungs?

When Gamow began thinking about this, scientists had already found an important clue. Astronomers had examined the spectra of countless stars and from the patterns of missing colours they had deduced not only which elements were absorbing the light but how common each element was. They had concluded that everywhere in the Universe the elements existed in roughly the same relative proportions.

To some this was an indication that a common process had built up all the elements, starting perhaps from the simplest, hydrogen. Indeed, there was a precedent for such an element-building process. In 1919, the New Zealand physicist Ernest Rutherford had bombarded a light element (nitrogen) with alpha particles and turned it into a heavier element (oxygen). Could nature have done the same thing?

The obvious site for building elements was inside stars. In the 1930s, the German physicist Carl-Friedrich von Weizsäcker had investigated plausible element-building nuclear reactions. He concluded that synthesis of all the chemical elements from hydrogen would require a furnace with a very wide range of densities and temperatures, increasing to billions of degrees. However, at that time everyone thought, incorrectly, that all stars were much the same as the Sun, which has a core temperature of only 15 million °C.

It was against this backdrop that Gamow began looking for an alternative site that could have forged the chemical elements. Where in the Universe was there a "furnace" that could reach a temperature of billions of degrees? Gamow realised the entire Universe must have been such a furnace when it was very young.

Over the previous decade or so, it had become clear the Universe is expanding. Run this expansion backwards, and the Universe would become hotter as it became denser, just as air in a bicycle pump heats up when it is compressed.

This led Gamow to suggest that the Universe was born in a "hot" big bang. He envisaged the early Universe as a searing hot mass of protons, neutrons and electrons compressed into a tiny volume. Something then triggered this mass to start expanding and cooling, and as it did so nuclear reactions among the basic ingredients forged all the elements. This must have happened in the first few minutes of the Universe's existence before the fireball became too cool and rarefied for nuclear reactions to continue.

But this theory didn't entirely fit the evidence. Although Gamow found that it was possible to make helium and other light elements in this way, it proved impossible to build the heavy elementswhatever mixes of initial ingredients he chose. The early Universe simply did not stay hot and dense long enough for a succession of nuclear reactions to build up elements such as oxygen and calcium. Gamow's theory was a miserable failure.

Inside stars

By the 1950s, however, the way that stars generate energy was better understood. Their interiors supported a far wider range of densities and temperatures than anyone had dreamed was possible. In fact, the hot interiors of stars have manufactured virtually every element heavier than helium.

Gamow's big bang theory had risen from the ashes of an idea about the cores of stars that was entirely wrong. Nevertheless, his achievement was immense. He was the first person to think seriously about the conditions in the early Universe. He also laid the foundations of the modern view that only particle physics can provide answers to the ultimate questions about the first few minutes after the Universe was born.

Gamow, Becquerel and Harvey were just three of many scientists who were right for the wrong reason. Evidence, if evidence were needed, that great scientific discoveries often come about in the most unexpected of ways and that the progress of science is not as logical as the textbooks would have us believe.

Bibliography

1. Further reading: Inward Bound by Abraham Pais (Oxford University Press),
2. Afterglow of Creation by Marcus Chown (University Science Books, California).

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