The Invisible Light
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Number 50.
Celebrating the 50th edition of 'The Invisible Light'.
Celebrating the Platinum Jubilee of her majesty Queen Elizabeth.

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The Invisible Light (50)

Contents:

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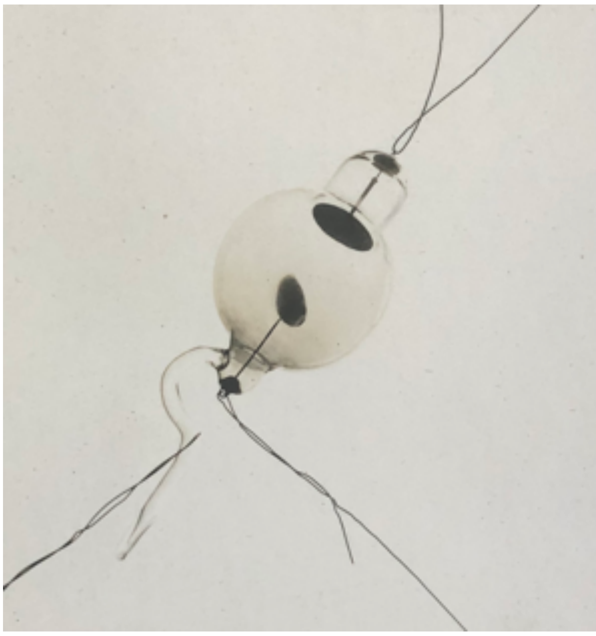
Editorial.

It is remarkable that this is now issue number 50! We have therefore two events to celebrate.

We are celebrating the 50th edition of 'The Invisible Light'. There have been many interesting papers published over the years, and many are reproduced on our website.

We are also celebrating the Platinum Jubilee of Her Majesty Queen Elizabeth, and send her our congratulations.

The metal platinum is of great interest to radiology, and the first true X-ray tube, which was designed by Herbert Jackson, had the anode made of platinum (see figure). Platinum was used because of its high melting point.



Herbert Jackson's first focus tube shown at the Royal Society in London in 1896. The cathode stream is focused on the anode (on the left side of the tube) which is at an angle of 45 degrees. This tube was originally part of the BIR collection, and was gifted to the Science Museum in London.

The image on the front cover is striking and remarkable. It is based on the portrait of Queen Elizabeth as depicted on the Machin definitive stamp as sown on this 2nd class stamp. In 1967 Edward Short, the then Postmaster General, exclaimed:

> "After months of extremely hard work by Mr Arnold Machin and the printers …. a design was evolved which in my opinion will be one of the classics of stamp history."

This has indeed proved to be the case.

The X-ray stamp image was created by Ernesto Romano (Instagram: romanoart) who is an Italian artist living and working in London. He uses his own X-Rays to create his artworks. He wrote to me saying:

> 'By using X-Rays, which he thinks are free from any prejudice or stereotype and the most judgemental free angle from which a person can be looked, he tries to convey a message of equality, diversity and inclusion. His series dedicated to Her Majesty The Queen reveals how the monarch's cultural influence can travel beyond borders, race, gender and social status.'

From his website www.ernestoromano.com he says:

> "First Lady and Royal Book are my homage to the iconic U.K. First Class Stamp which features Her Majesty The Queen.
> This re-interpretation uses my X- Ray of the Queen's profile combined with the well-known 1st font used on the first class stamp.
> What I want to convey with this series is that all humans are equal: regardless of crowns and jewels we wear, we all look the same under the skin."

And this is true. The radiograph reveals the truth that we are all walking skeletons. However as a radiologist I would have to disagree with Ernesto a little. We all look different on the outside, and we all look different on the inside. Basically we are variations on an anatomical theme.

The images can be purchased on his web site and are available in a variety of media and colours. I thank him for allowing me to reproduce his remarkable image.

………………………………..

Sadly Grahame Mountford (1927-2022) died earlier this year. He was a longstanding member of our committee, and was our treasurer for many years. A tribute to Grahame Mountford was president of the . BIR and I wrote a tribute which can be found at: Website. https://www.bir.org.uk/media-centre/news/2022/january/a-tribute-to-grahame-mountford.aspx

Grahame Mountford (second from the right) as a young radiographer.

Please send me any articles that may be used in issue 51!

Adrian Thomas
adrian.thomas@btinternet.com

Recent Aunt Minnie Europe Articles:

Under scrutiny: 100 years of articles about contrast agents (November 11, 2021)
https://www.auntminnieeurope.com/index.aspx?sec=sup&sub=mri&pag=dis&ItemID=620814
U.K. radiology mourns MSK specialist Charles Wakeley (November 19, 2021)
https://www.auntminnieeurope.com/index.aspx?sec=sup&sub=mri&pag=dis&ItemID=620851
U.K. mourns loss of interventional radiologist David Shepherd (February 4, 2022)
https://www.auntminnieeurope.com/index.aspx?sec=sup&sub=cto&pag=dis&ItemID=621104

Interesting web sites.

Oak Ridge Associated Universities (ORAU) Museum of Radiation and Radioactivity.
https://www.orau.org/health-physics-museum/index.html

The purpose of the Oak Ridge Associated Universities (ORAU) Museum of Radiation and Radioactivity is to chronicle the scientific and commercial history of radioactivity and radiation. It has been deemed the official repository for historical radiological instruments by the Health Physics Society, and the Society has been generous in its financial support for the purchase of items.

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New Books.

Imagining Imaging [Print Replica] Kindle Edition
by Michael R. Jackson (Author) Format: Kindle Edition
Publisher : CRC Press; 1st edition (25 Nov. 2021)
Kindle Edition £35.14 Hardcover £110.00 Paperback £36.99

Michael Jackson is a member of our Committee and is a Consultant Paediatric Radiologist at the Royal Hospital for Children and Young People in Edinburgh. He has just taken up the role of Chairman of our British Society for the History of Radiology, and is also Archivist to the Scottish Radiological Society. Michael has an interest in the history of medicine and radiology that is longstanding. He is the Royal College of Radiologists/British Society for Paediatric Radiology Travelling Professor for 2021-22.

In **Imagining Imaging** Michael has produced a remarkable book. As the blurb says, it ranges from Röntgen to Rembrandt, from Godfrey Hounsfield to Hollywood, and from Andreas Vesalius to modern videogames. And so we are told that **Imagining Imaging** explores the deeply entwined relationship between a visual-based culture and medical imaging. The book includes artworks from numerous historical eras and so represents varied geographic locations and visual traditions, including diverse range of contemporary artists. In reality the boundaries between disciplines are far more fluid than might be imagined. The boundaries between various sciences are blurred, as is the boundary between art and science. The question 'What is Art?' has been asked by many and has had a variety of responses. For Leo Tolstoy writing in 1897, just after X-rays were discovered, art is a human activity which consists in conveying feelings (emotions) by external signs. Therefore for Tolstoy art doesn't simply consist in creating beauty or pleasure or in expressing emotions, but in reality lies in infecting people with feelings. It should be remembered that the term 'art' is derived from the Latin word 'ars' which means an art, skill, or craft. Both the radiologist and the artist practice their respective crafts. Is there then a meaningful difference between the artisan and the artist, or is it simply a question of context? Diffusion MRI images showing the white matter tracts of the brain, so-called tractography, appear very like art created by an artist. The artist working with medical images blurs the art and science distinction and will give us new insights into ourselves. There is also a concomitant blurring of the distinctions between art and science, and the two cultures of art and science no longer seem so divided to us now as they were to C.P. Snow writing in 1965.

Michael sees the foundations of medical image construction and interpretation as arising from historical artistic innovation. The book is a fascinating admixture of art, science and medical history, with elements of neurophysiology and psychology. It is beautifully illustrated with many coloured illustrations which are shown particularly well on the Kindle version. The book is warmly recommended.

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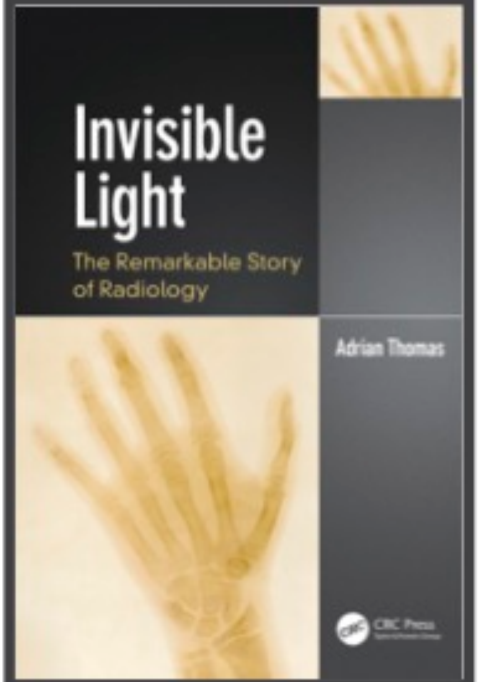

March 2022: 6.14 x 9.21: 332pp
162 illustrations

Hb: 978-0-367-34426-9 | £38.99
eBook: 978-0-429-32574-8

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7. Radiologically guided intervention.
8. Contrast media.
9. Radiology and women.
10. Tomography: mechanical to computed.
11. NMR to MRI.
12. The Future.

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Adrian Thomas

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LH Gray: Physicist and Radiobiologist.
His life; his laboratory and his legacy.

By Edwin Aird.

Preamble: Physics and Medicine.
At the beginning of the 20th century there was a dual purpose for establishing a profession for physicists in medicine. One was the question of teaching physics in medical schools and the other was the measurement of ionising radiations, following the discovery of X-rays and radioactivity. The earliest appointments in medical schools were Lloyd Hopwood at Bart's and James Brinkworth at St Thomas', both in 1906 [1]. However in his article "The life and times of Sidney Russ (1879-1963)" Francis Duck writes about Russ' early career in the 1930s, "He worked with Helen Chalmers: together they set up and tested the first radium bomb in Britain using 5g radium bromide. Chalmers was the first doctor to state clearly that the physicist was an essential part of the radiotherapy team alongside the surgeon, radiologist and pathologist".

(note: the title "radiologist" at that time referred both to a physician working in the X-ray imaging department or the clinician in the treatment of cancer with X-rays and radium).

[Prior to the work of a physicist in their work with Radium clinicians were prescribing radium treatments empirically, in terms of quantity of radium (in milligrams) for a given length of time that had been determined empirically: e.g. 1915: for Bladder Carcinoma, a quantity of radium: 25mg, 50mg or 75 mg for a total of 60 hours].

Russ was appointed as the first Joel Professor of Physics in the Middlesex Hospital Medical School in 1920, which "established Russ as the leading British scientist in medical radiation physics".

The 1920s and 1930s were noted for the development of physics and engineering as applied to medicine, particularly radiology. By 1932, (according to Eric Roberts' book "Meandering in Medical Physics"), there were around 12 posts for physicists in hospitals and medical schools. For example, higher voltages were needed to get more penetrating radiations, and a generator which was installed in Bart's by George Innes and Raymond Quick at up to one million volt (1

[1] Editorial note: Whilst Hopwood and Brinkworth may have been appointed in 1906 the history is considerably older. Medical physics in medical training in London is discussed by Francis Duck in his *Physicists and Physicians : A History of Medical Physics from The Renaissance to Röntgen* (IPEM, 2013). Francis notes that Thomas Griffiths was a lecturer giving courses on natural philosophy/physics at St Bartholomew's Hospital in 1834. By 1899 Francis writes that Edith Stoney was employed full-time as a lecturer at the London School of Medicine for Women. Her academic status was proudly declared in the Annual Report: 'Physics Lecturer: Miss E. A. Stoney, Cambridge Mathematical Tripos Pt.I. and Pt.II. Associate of Newnham College Cambridge.' These qualifications were very important as the London School of Medicine for Women strove to establish its status and credentials. At this time, medical students at Guy's were taught physics by Professor Arnold Reinold from the Royal Naval College at Greenwich, and at University College by Professor (later Sir) William Ramsay. The professors who gave lectures in physics in the medical schools outside London were even more impressive: Oliver Lodge in Liverpool, Arthur Schuster in Manchester, John Henry Poynting in Birmingham, JJ Thompson in Cambridge. Edith's cousin George FitzGerald was teaching physics to the medical students at Trinity College. It was a time when a sound grounding in physics was considered to be an essential part of medical training. See: A Thomas, & F Duck: *Edith and Florence Stoney, Sisters in Radiology* (Springer Biographies, 2019.

MV) using a Cockcroft/Walton generator (a special voltage multiplier, also used by Cockcroft and Walton when they split the atom in 1932 at the Cavendish Laboratory; and Gray and Read used for their neutron generator, see below). By the time of the second world war there were somewhere between 35 and 40 posts for physicists in medicine.

References:

Jennings W A. (2004) A Brief History of the Evolution of Medical Physics in the United Kingdom in the Twentieth Century. The Invisible Light. Journal of the Radiology History and Heritage Charitable Trust 20: 34–6.

Jennings W A, Russ S. (1948) Radon: Its technique and use. London:

Phillips R S, Innes G S. (1938) Physical measurements in high voltage X-ray therapy. British Journal of Radiology 11: 498–503.

Gray: His early Years.

Gray was born in Barnes, South London on the 10th of November 1905 to poor parents. He attended Latimer School (London) where, at 13 , he won a scholar ship to Christ's Hospital (in West Sussex), where he boarded.

He was not particularly interested in the humanities; his "consuming joy" was physics and then maths. And then at the age 18 molecular physics inspired him. He gained an exhibition scholarship to Trinity where he studied Physics, Maths and Chemistry in Part 1 of the Natural Science Tripos. He added mineralogy for Part II.

This led on to his working/studying at the Cavendish Laboratory 1928-1933 (where some staff at the time were: Chadwick, Thomson, Rutherford (Professor at that time), Cockcroft, etc. (see photo). He studied the interaction of radiation with matter (using cosmic radiation, then "hard" - that is high energy- X-rays), and awarded his PhD and prize fellowships at Trinity. In 1932 Chadwick discovered the neutron at Cavendish. Neutrons were used by Gray later in his career when he became interested in the different Relative Biological Effectiveness (RBE) for neutrons compared with photons on living tissue, which was not known at that time.

According to Jack Boag in his Obituary for Gray in 1965 (BJR 38: 706-707), he (Gray) claimed "Throughout his life Rutherford was his ideal of a leader of scientific research, and in his own laboratory Gray he set out to create a "Cavendish" atmosphere."

Chadwick was his supervisor while Gray was gaining an understanding of ionisation by photons and developing a theory of the relationship between ionisation and absorbed energy (to become the "Bragg-Gray" theory, see below). It was Chadwick who encouraged him to apply for a post at Mount Vernon Hospital (MVH) in Northwood. This appointment of a physicist would include some routine work; but would mainly be research based, under Sir Cuthbert Wallace (Hospital Director). Gray arrived at MVH in 1933.

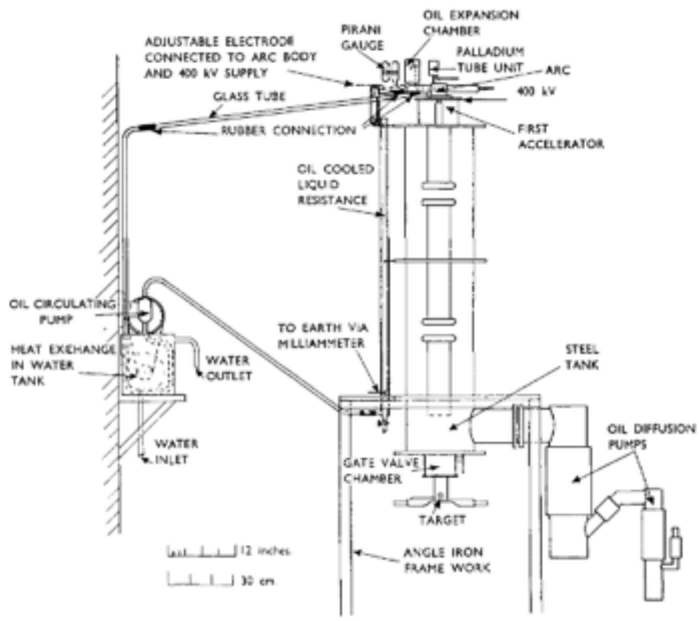
Fig. 1: Staff at Cavendish 19 (front row: P Kapitza, CD Ellis, J Chadwick, Prof Sir JJ Thomson, Prof Sir E Rutherford, Prof CTR Wilson, FW Aston, JD Cockcroft, WH Watson)

Gray's Co-Workers at MVH.
Before we look at Gray's work at MVH it is important to acknowledge the work of J. C. Mottram, the pathologist at Mount Vernon Hospital. Mottram had worked at the Cancer Research Laboratories with Professor Sidney Russ(see Preamble above). Russ wrote in his obituary: " …he was for years the outstanding pathologist in this country, to whom radiologists looked for authoritative opinion and with whom they collaborated actively on a large variety of subjects". This is evident from Mottram's extraordinary body of work in 1908-1940. Mottram then became Director of Research Department at the Radium Institute and with the change in status of MVH (as a hospital mainly for cancer patients rather than patients with TB) became Director of Pathology Research at MVH in 1931 until his death in 1945.

John Read, who had also been working at the Radium Institute in London, then came to join Gray at MVH. They started to work together with a grant from British Empire Cancer Campaign (BECC) to cover Read's salary and the cost of materials to build a 400kV Cockcroft/Walton generator (similar to that developed at the Cavendish Laboratory) and an ion tube to accelerate deuterons onto a deuterium target to produce high energy neutrons. MVH provided a wooden shed to accommodate the equipment. This pair built their own neutron generator to save money.

Fig. 2a. Original Wooden Hut built with Read in 1933.

2b. Neutron Generator developed and built with Read



On 9th June 1938 they did their first biological experiment with Dr. M.G. Spear: the inhibition in chick fibroblast tissue cultures by neutron irradiation. The first irradiation of the broad bean – Vicia Faba - was in 1938 (which was the beginning of a huge series of experiments with different radiations, and resulting in 3 letters to Nature in 1939 and a considerable number of papers to BJR during that period (see references).

Scientific outcomes during 1935-1941 by Gray, Read, and others:-

Measurements of dose from fast neutrons and alpha particles.

RBE for killing of broad bean root: gamma rays; neutrons; x-rays; alpha particle.

John Read: *"It is a matter of deep regret that Hal Gray dies before the explanation for the dependence of RBE on LET had been convincingly established. I regard the five years that we worked together as the most stimulating and happy ones of my life. I have never recaptured the enthusiasm and thrill of those days."*

3. On the physics side: Gray was developing his theory, which he had started working on at the Cavendish, on the use of ionisation chambers to measure absorbed energy (dose). This was based on an idea of Bragg 1911: to be able to covert an exposure measurement into energy absorbed by 1 gm of water. Although most of the concepts and work on this subject were mainly his, Gray because of his modesty, called the result *The Bragg-Gray theory*. [The Gray (Gy): a unit of absorbed dose, was adopted by the ICRU in 1975, and is now in common usage when prescribing radiotherapy treatment dose].

Gray received the Roentgen award from BIR in 1938. Along with other colleagues around the country the HPA [The Hospital Physicists Association, now known as IPEM, was formed in September 1943 under the chairmanship of Prof Sidney Russ of the Middlesex Hospital. Gray was president of the HPA from 1946-1947].

In 1946 he moved to Hammersmith Hospital as Senior Physicist initially, then deputy director of the MRC Radiotherapy Research Unit. With access to the new cyclotron at Hammersmith he was able to continue his work on the role of oxygen in cell/tissue response.

Major developments were taking place at Hammersmith post-war. The MRC was developing biological aspects of developments in Nuclear Medicine to the existing Radiotherapy Research Unit. Gray was the senior physicist in this group (Others working there at this time: Normal Veall; Alma Howard; Tikvah Alper; Michael Ebert; Oliver Scott). He was working with Constance Wood as director, having the remit to develop techniques for diagnosis using radioisotopes produced in the cyclotron. The cyclotron was also designed to produce neutrons suitable for radiotherapy.

There were delays to the programme, and less money was available, which put pressure on the director to choose an exciting direction for the research of the group. Wood was keen to be able to use neutrons in patients as soon as possible ; whereas Gray could see that much more experimental work was needed to understand the RBE of neutrons in patient tissues. (He already knew that oxygen was critical in augmenting radiation damage; but also that there was not a full understanding of the differences between x-ray damage and neutron damage.) By 1953 these differences led to breakdown in relationship between him and Constance Wood.
MRC stepped in and Gray was given 6 months leave on full pay.

He wrote one of his definitive papers at that time:
(Gray, Conger Ebert, Hornsey and Scott BJR 1953) …demonstrating his belief in the importance of oxygen tension within the tumour as a major factor affecting the action of radiation on living cells……(and affecting the future work of The Gray Laboratory…see later)

However, BECC was able to create a Nuffield Fellow post at his old hospital MVH, to build a new laboratory.

New Beginnings at Mount Vernon Hospital.
There wasn't enough money for staff and buildings at MVH, but a very generous donation was made from Oliver Scott's family trust (The Scott of Yews Trust).
Oliver Scott had worked with a colleague at MVH : Hugh Thomlinson on the development of necrosis in human tumours. He introduced Gray to Thomlinson and together the constructed the Thomlinson-Gray model for the development of chronic hypoxia in tumour tissue (Br J Cancer 1955). Gray also worked in physical chemistry and recruited Jack Boag, Barry Michael, and David Dewey to his team.

Fig 3a: Gray in front of New laboratory at MVH.

Fig 3b: LH Gray as President of BIR 1949-1950.

Some work of the group from 1954:

- Establish equipment for producing various ionising radiation beams and an animal house for small animals to be irradiated.
- Studies in radiolysis (J Boag, who also described the solvated electron and measured its absorption spectra).
- David Dewey was the first to demonstrate the change in radiosensitivity with pO2 for cells irradiated in vitro.
- Later, Ged Adams (1962-1976) started the development of hypoxic cell sensitizers.

During his short period as director Gray had a particularly able graduate student studying for his PhD, H Rodney Withers, who went on to evaluate the radiation sensitivity of various tissue in experimental animals leading to an extraordinary impact on our understanding of dose fractionation in radiotherapy (refs: Withers.1975, 1983). [Withers later became head of the Department of Experimental Radiotherapy at the MD Anderson Cancer Center (University of Texas)]

The laboratory was officially opened on 20th May 1957 by His grace the Duke of Devonshire, Chair of the BECC and known as the "Research Unit in Radiobiology" (RUR) at that time.

Gray's work was already recognised abroad. In 1952, at the 1st Radiation Research Society meeting in Iowa City, he was invited to speak and presented; "Some Characteristics of Biological Damage Induced by radiation". At this meeting he threw down the challenge to all the varied scientists present to build on his work. His mood was "one of enthusiasm and optimism, almost gaiety, over the exhilarating intellectual experiences offered".

So when the Association of Radiation Research decided to organise its 2nd International Congress of Radiation Research (to be in 1962), they appointed LH Gray as chairman; Alma Howard as General Secretary and Oliver Scott as a member of the organising committee. (For some reason this couldn't be in London and Harrogate was chosen as the venue for the meeting: around 1300 attendees).

However, Gray threw himself into this new role for two years which exhausted him. He may not have recovered from this effort and died from a stroke in 1965. The RUR was renamed the Gray Laboratory in 1971.

His main legacy, discussed by Peter Wardman (Gray Lab 1973-2008) and Philip Dendy: BJR 2006 "Hypoxia in biology and medicine: the legacy of LH Gray":

> (PW): "Gray must have been the first-and quite possibly the last-scientist to have a thorough appreciation of current activity in all four sectors of radiation research: physics, chemistry, biology and medicine".
> (PW & PD)"Had he not died so young he may well have received a Nobel prize" "…drawing attention to the importance of tumour hypoxia is the most important legacy of L H Gray. "Establishing radiobiology as a new, rigorous , scientific discipline".

Some of the awards given to Gray:

Honorary Member of the Hospital Physicists Association
1938 BIR Rontgen Award
1953 Sylvanus Thompson 3rd memorial lecture: "The initiation and development of cellular damage by ionising radiation"
1954 Katherine Berkan Judd Award (from Sloan Kettering Institute)*
1956-1958 Vice Chairman of the ICRU; and also served on ICRP.
1960 The Barclay Medal
1961 Fellow Royal Society
1962 Honorary Degree of D.Sc. from Leeds University
1964 Bertner Foundation Award Lecture (MD Anderson Hospital)*
1967 ICRU announced the establishment of a medal honouring the late Louis Harold Gray **

*EL Powers (1965) states: "That these two awards should go to a physicist-turned radiation biologist-is an uncommon honour ……He was the most knowledgeable and most effective bridge between radiation physics, chemistry and biology and radiation therapy. These awards as his election to honorary membership of the American Radium Society (the only non-physician other that William Coolidge so elected), are testimonies to the very high regard in which he was held by the clinicians of America."

**Elenor Blakely received the 20th Gray Medal in 2019 : Health and Heavy Ions.
She identified 6 Radiation Pioneers for hadron therapy:
Ernest O. Lawrence invented the cyclotron in 1931 and received the 1939 Nobel Prize in Physics: Sir William Henry Bragg first reported the Bragg Curve (peak) in 1903: Louis Harold Gray, the Father of Radiobiology, developed the Bragg-Gray equation and the concept of Relative Biological Effectiveness in 1940 and discovered the role of oxygen in radiation effects on tumour cells in 1952, and discovered the hydrated electron 1962 ;Robert Wilson proposed the use of the Bragg peak for radiation therapy; John H Lawrence was the Father of nuclear medicine and treated the first patient with protons; Cornelius A Tobias was the Father of Heavy Ions radiobiology and investigated the biological effects of protons and heavy ions.

The Laboratory after Gray.
Immediately following the death of Gray, Oliver Scott stepped in as director of the lab. He had a great deal of experience understanding oxygen physiology. However, he had to resign in 1969 for health reasons. [In later life "he played an important role in the PUGWASH antinuclear weapons group; together with Prof Joseph Rotblat, founder of the group]

To give an indication of the growth of the laboratory after that year (under the directorship of Professor Jack Fowler) , in 1982 (25th anniversary see photo) there were 70 staff (20 with PhDs) plus visiting students and staff from around the world, with the following groups:

Tumour radiobiology in vivo and in vitro (Nick McNally)
Radiobiology applied to radiotherapy (Julie Denecamp)
Molecular radiobiology (Peter Wardman)
Biochemistry and microbiology(David Dewey)
Biophysics and Engineering (Barry Michael)
Administration (Wg. Cdr. Hunter, Mrs Collins, Prof Fowler)

In 1978 Jack had appointed Julie Denecamp as Head of RB applied to Radiotherapy to investigate the effect of fraction size with an emphasis on repair mechanism ; and to explore the dissociation of acute and late effects, particularly when considering new treatment modalities. By this time the clinical team at MVH (led by Stan Dische together with Michele Saunders) had already developed, in collaboration with the Gray, CHART (Continuous Hyperfractionated Accelerated Radiotherapy: 36 fractions; 3 fractions per day; no weekend breaks; total dose 54Gy) as a new method of treating non-small cell cancers of the lung and Head and Neck.

Julie assisted the development of CHART in 1980s and on Jack's retirement in 1988 became the director of the Gray. The main work of the lab at that time included:
pre-clinical studies of different fractionation regimes for radiotherapy; work with radiosensitizers and protectors; hyperthermia; and cell proliferation kinetics.

Julie expanded the space within the laboratory to 230 rooms. She also refurbished the chapel (an Art Nouveau building used by the patients when MVH was a TB hospital, when the patients couldn't be allowed into the town) into a conference centre with seating for 200 delegates and an amazing sound system developed by Boris Vojnovic. The chapel became known as: The Fowler-Scott Library. This facility was immediately used during Jack's retirement year. Several meetings were organised with participants from all over the world:

A Symposium on 30th March with 132 attendees; A conference: " The scientific basis of modern radiotherapy" 30th June-2nd July with 145 delegates. Followed by a course for Radiotherapists " Radiobiological Basis of Modern Radiotherapy" with 25 participants.

The salary and consumable budget at that time amounted to almost £1.8 million a year , entirely supplied by the Cancer Research Campaign]
However, the first signs of potential funding problems for the Gray Lab are stated in the annual Gray Lab report for 1992:" In the early 1990s Julie became the victim of strategic attempts by Head Office (CRC) to reduce the amount of investment in radiation research" This led her to leave in 1994 to continue her work full time in Umea. While the Gray Lab continued in a slimmed down form, as a Trust instead of wholly owned by CRC.

Fig. 4: The Staff of the Gray Laboratory in 1982 .
J Denecamp in the centre with B Michael on her left, then J Fowler; On her right is P Wardman.

The Next Director: Prof G E Adams retired as Director of the MRC Radiobiology Research Unit to become the first Chairman of the newly established The Gray Laboratory Cancer Research Trust in 1995 at which time about 80 staff were employed by the Trust (+ several visiting research staff). His major plan for the Lab was a new building to house a 4.7T MR facility (to be run by Dr Ross Maxwell) for small animal in-vivo imaging and fMRI). A small PET scanner was also planned together with a joint plan with MVH and Paul Strickland Scanner Centre to operate a cyclotron for the production of standard PET isotopes and research into new isotopes to aid imaging of special cancers. The upper floor was to house a new Molecular Medicine Group, which was to be concerned particularly with programmes in hypoxia based gene therapy and also joint laboratory facilities with the Department of Pathology at MVH (a full circle when thinking of Gray's first work with Mottram in 1938).

The beginning of the end.
Very sadly Ged died in June 1998 before completion of this project. The Ged Adams building was opened by his widow in December 1998.

The Gray Lab continued to thrive under the Chairmanship of Prof. Stanley Dische (who had retired from Head of Cancer Services at MVH in 1998) , but with the extra burden on the Heads of Section and laboratory staff generally of the need to apply for grants to continue their work (1999 forty one applications under consideration: £10k-£1m +). In 2001 the Gray Laboratory was renamed the Gray Cancer Institute.

The Final Years.
In the 2002 GLI Research Report Prof. Dische wrote: " Much time has been devoted to the preparation of detailed proposals to Cancer Research-UK and these were finally completed and presented at the end of the year. We look forward in 2003 to a successful negotiation with CR-UK and UCL"

However, Prof Dische resigned his chairmanship at the end of 2003 and Prof David Harnden took on this role for a brief period . A special symposium (in the Fowler-Scott Library) to honour Sir Oliver Scott's 80th birthday was held in April 2003 (the year of 50th anniversary of the famous Gray, Conger, Ebert, Hornsey and Scott paper defining the "concentration of oxygen dissolved in tissues at the time of irradiation as a factor in radiotherapy"). The theme of the symposium was "Oxygen". Speakers included : Rod Withers, Jack Boag and Jack Fowler. At this time also, the Julie Denecamp Memorial garden was opened by Bo Littbrand.

An internal review found that, to secure the Institute's future it should move to an environment with a supportive research base. In 2004 Gillies McKenna was appointed Honorary Director and in 2008 the Institute relocated to Oxford to be n 2004 Gillies McKenna was appointed Honorary Director and in 2008 the institute relocated to Oxford to be within the CRUK/MRC Oxford Institute for Radiation Oncology.

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The Gray Laboratory Legacy (Some Aspects).
1) From : "BJR Pushing the frontiers of radiobiology: a special feature in memory of Sir Oliver Scott and Professor Jack Fowler BJR 2018; 92/1093"

In particular there were two recent papers connected with hypoxia:

Thamralingham H, Hoskin P. Clinical Trails targeting Hypoxia.

> "It was not until the seminal studies of Gray and colleagues in the 1950s that the role of hypoxia was established as a major cause of radiation resistance. In their pioneering work, they demonstrated that hypoxia caused resistance to radiation in a broad spectrum of microbial, plant and mammalian cellular models using a variety of different end points."

Tumour oxygenation and cancer therapy- then and now. Hughs VS, Wiggins JM, Siemann DW

> "The landmark publication of Thomlinson and Gray, which evaluated histological structures of human lung cancers (Figure 1), concluded that, "there must exist a falling gradient in oxygen tension between the periphery and the centre of each tumour cord".

These findings implied that tumour cells near the limit of oxygen diffusion would survive at lower than normal oxygen tensions, rendering them resistant to radiation therapy.

2) John Yarnold and Breast Cancer Fractionation.
The work of Jack Fowler and his colleagues was to have an impact on fractionation schemes in the UK and beyond. in particular the use of hyperfractionation and the CHART trial (see above). But it was during Jack's years at the Gray that John Yarnold (Clinical Oncologist at ICR) was influenced by his work: "My first exposure to Jack Fowler and Oliver Scott was at the Gray Lab and Mount Vernon Hospital in June 1975, during the very first RCR 1 week radiobiology course organised by Hugh Thomlinson for first year trainees. [Hugh Thomlinson followed Gray to Mount Vernon in 1974 where he started on his life's work of measuring tumours in situ before , during and after treatment, (see Tomlinson's earlier work with Gray 1955)]

"A few days contact with these individuals did more than anything else to stimulate in our student group a lasting interest in clinical radiation biology. In the years that followed Jack Fowler became a leading interpreter of the linear quadratic model developed by Rod Withers and colleagues. No better summary exists of the early history of fractionation, including hypofractionation, than that written by Julian Hendry for a review of UK practices published by the RCR in 2006"

Bruce Douglas used L Cohen's data to show values of beta/alpha. But it was John Yarnold who began to interpret the meaning of the inverse, alpha/beta, for breast cancer. John began, what has now become about 30 years of breast cancer radiotherapy trials moving steadily towards extreme hypofractionation. One of The latest trial (FAST Forward) has reported. (The Lancet 2020). In among these trails John also looked at how to give partial breast radiotherapy accurately and efficiently (IMPORT etc). [Oxford paper: " The future possible outcome is a 1week schedule for whole or partial breast that not only improves the balance of local control and adverse effects-but also reduces the physical, emotional and economic burden of classical treatment schedules…….(we) undoubtedly owe a debt to the inspiration and encouragement offered by Jack and Oliver to several generations of radiation oncologists"]

3) Fractionation Generally.
"How worthwhile are short schedules in radiotherapy?: A series of exploratory calculations. (Radiother. Oncol. 1990; 18: 165-181] demonstrates Jack's input into this vital subject. In particular he established the α/β ratio for prostate cancer which has allowed clinicians (in particular: D Dearnaley; Lancet Oncology 2016) to clinically trial shorter radiotherapy regimes; which , together with the work of John Yarnold for breast has helped establish hypofractionation in UK which has also helped radiotherapy centres throughout the world cope with patients throughput during the Covid 19 epidemic.

Addendum: a radiobiology brief into the linear quadratic model.
Jack was to become one of the main proponents of the linear quadratic model which has been found to satisfactorily describe the relationship between total isoeffective dose and dose per fraction. In this model the α/β ratio describes the shape of the dose-response curve when radiotherapy is given in multiple fractions: a low α/β is characteristic of late responding tissues; a high α/β is characteristic of tumours. Radiotherapy regimes already in existence, prior to a fuller understanding of radiobiology using the α/β model, used large number of fractions to eliminate tumours while saving normal tissues. In the last 2 decades, our greater understanding of α/β model , particularly for breast and prostate tumours has, with the evidence from excellent clinical trials , encouraged the use of shorter fractionation regimes: e.g.: in Breast : 1 fraction/week for 5 weeks (and possibly daily fractionation for 1week of 5 fractions), instead of daily fraction for 4-5weeks; in prostate 15 fractions over 4 weeks instead of 30 fractions over 6-7 weeks. During the recent Covid epidemic these regimes have been used widely throughout UK and Europe to help keep waiting list down for radiotherapy (RCR 24th March 2020: "Deliver RT in 5 fractions only for all patients requiring RT with node negative tumours that do not require a boost. Options include 28-30Gy in once weekly fractions over 5 weeks or 26Gy in 5 daily fractions over 1 week as per the FAST and FAST Forward trials respectively" see John Yarnold above.

References:
Gray LH. The photoelectric absorption of gamma rays. Proc. Camb. Phil. Soc.1931; 27, pt. 1: 103-112
Gray LH and Tarrant GTP The nature of the interaction between gamma radiation and the atomic nucleus. Proc. Roy. Soc. A 1932; 136: 662-691

Gray LH. An ionisation method for absolute measurement of gamma-ray energy. Proc Roy Soc A 1936; 156: 578-596
Gray LH, Radiation Dosimetry Pt 1 Brit J Radiol 1937; 10: 600-612
Gray LH, Radiation Dosimetry Pt II Brit J Radiol 1937; 10: 721-742
Gray LH, Spear FG and Read J. Biological effects of fast neutrons. Nature 1938; 142:1074
Gray LH, Read j, and Wyatt JG. A neutron generator for biological research. Brit J Radiol 1940; 13: 82-94
Gray LH and Read J. The effect of ionising radiations on the broad bean root.
Pt I General notes. Brit J Radiol. 1942; 15: 11-16
Pt II The lethal action of gamma radiation. Brit J Radiol. 1942; 15: 39-42
Pt III The lethal action of neutron radiation. Brit J Radiol. 1942; 15 72-76
Pt IV The lethal action of alpha radiation. Brit J Radiol. 1942; 15: 320-336
Gray LH and Read J. Treatment of cancer by fast neutrons. Nature 1943; 152: 53
Gray LH, Conger AD, Ebert M, Hornsey S, and Scott OCA. The concentration of oxygen dissolved in tissues at the time of irradiation as a factor in radiotherapy. Brit J Radiol. 1953; 26: 638-618
Gray LH. Some characteristics of biological damage induced by ionising radiation. Rad Res 1954 1: 189-213
Gray LH Oxygenation in radiotherapy. 1 Radiobiological considerations. Brit J Radiol. 1957; 403-406
Thomlinson RH , Gray LH . The histological structure of some human lung cancers and the possible implications for radiotherapy . Br J Cancer 1955; 9:539-549
Withers HR. The four R's of radiotherapy. Adv Radiation Biol. 1975; 5: 241-7
Withers HR, Thames HD and Peters LJ. A new isoeffect curve for change in dose per fraction. Radiother. and Oncol. 1983 1: 187-191
Suit H. Contributions of LH Gray to radiation physics , biology and oncology. Int J Rad. Oncol. Biol. Phys. 2002; 53: 795-797
Dendy PP and Wardman P . Hypoxia in biology and medicine: the legacy of LH Gray. Brit J Radiol. 2006;
RCR The Royal College of Radiologists 2020. Coronavirus (COVID-19): cancer treatment documents

Obituaries:

Loutit JF and Scott OCA. Louis Harold Gray 1905-1965. Biographical Memoirs of Fellows of the Royal Society. November 1966.
Boag JW. Obituary LH Gray MA; PhD; D.Sc. (hon); FRS. Brit J Radiol. 1965; 38: 706-707
Louis Harold Gray. Obituary . LH Gray Trust website
Howard Alma. Louis Harold Gray. Int J Radiation Biology and Related studies in Physics , Chemistry and Medicine . 1965; 9: 509-511
Powers E L. Louis Harold Gray: An American View. Brit J Radiol 1965; 38: 804-5

Other Sources:

Wynchank S. Louis Harold Gray: A Founding Father of Radiobiology. Springer 2017
Gray Lab Annual Reports : Particularly : Silver Jubilee edition celebrating 25 years 1957-1982 of The Gray Laboratory.

{The BIR was particularly influential at in Radiotherapy and Radiobiology at this time [some presidents names up to 1978 – always alternating Physicists with Clinicians: LH Gray 1949-1950; JE Roberts 1951-1952; FW Spiers 1955-56; F Ellis 1963-964; J Rotblat 1971-1972; FT Farmer 1973-74; J W Boag 1975-1976; J Fowler 1977-1978].}

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Röntgen's crystal ball.

By Francis Duck
Bath, UK: bathduckf@gmail.com

'Röntgen's other experiment'.

'Röntgen's other experiment' was the title selected by Peter Dawson for his historical article, published in 1997 in the British Journal of Radiology [1]. The title was both eye-catching and misleading. Eye-catching because the phrase emphasised that Röntgen was not a scientific one-hit wonder, and that he should not be considered only as the physicist who discovered x-rays. In 1888, still at Geissen, he had demonstrated the existence of the displacement current in a dielectric, predicted by Maxwell's electromagnetic equations. His discovery was called the 'Röntgen current' by his colleagues.

Röntgen and piezoelectricity.

But the title of Dawson's article was also slightly misleading. This was not Röntgen's only 'other experiment'. He was a consummate experimentalist with a wide-ranging interest in all aspects of physics. He had published eighteen papers during his fertile ten years at Geissen on a variety of other challenging topics. The present article concerns three of these papers, on the electrical behaviour of quartz. Such is the dominance of his discovery of x-rays that they have been barely mentioned by his biographers. Yet, at the time, Sir William Thompson, then editor of the London Edinburgh and Dublin Philosophical Magazine and Journal of Science (known as Phil Mag) considered them to be so important that he arranged for all to be translated into English and republished in his journal. Histories of piezoelectricity, and hence histories of ultrasound, make note of these important contributions by Röntgen, which confirmed and extended the discovery of the piezoelectricity of quartz and other crystals by Jacques and Pierre Curie in 1881 [2] (Figure 1). By extending the Curies' work, Röntgen's evidence later supported the ideas of Paul Langevin when, in 1917, he realised how a quartz crystal should be used to make an efficient ultrasound transducer.

The Curies' discovery of piezoelectricity.

Röntgen's experiments followed immediately from the discovery of piezoelectricity by the Curie brothers. They had presented their work in a series of short publications during the period 1881-1883, followed by a summary in 1889, once Jacques Curie's had completed his PhD [3]. The Curies had discovered that compression of a slice of quartz cut *in a specific direction* caused the faces to become electrically charged, and also the reverse, that a voltage applied across these same faces caused the crystalline slice to expand or contract. This direction is called the electrical axis.

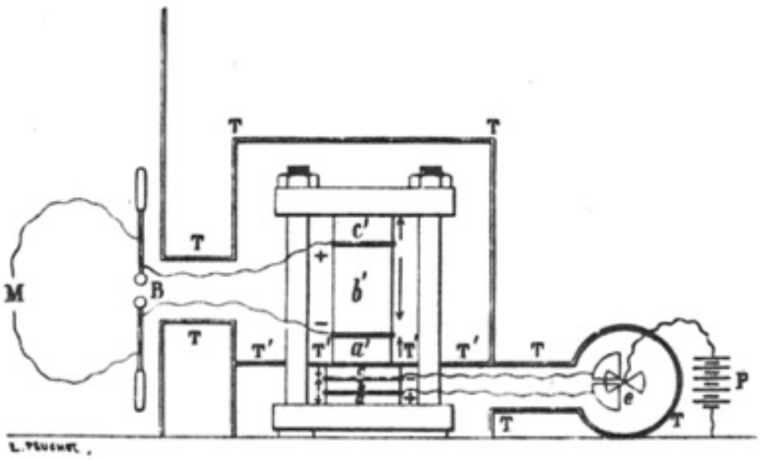
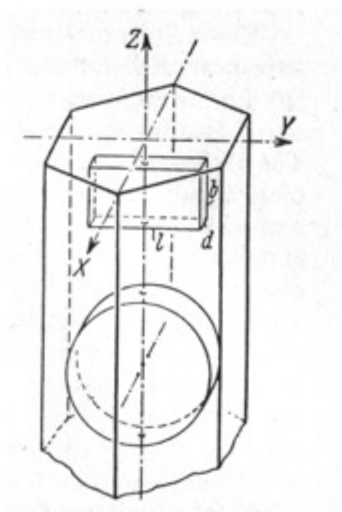


Figure 1. The apparatus used by Jacques and Pierre Curie to demonstrate the reverse piezoelectricity of quartz in 1882. A thick quartz triplet a'b'c' is caused to dilate by applying a high voltage. It is clamped to a thin quartz triplet a,b,c. The surface charge created by its compression is measured.

It was not a case of taking any quartz crystal, squeezing it anyhow and slapping electrodes anywhere. The orientation was key. Quartz crystals form as hexagonal prisms, giving a three-fold symmetry in one plane (Figure 2). There are three electrical axes, all orientated through the edges of the hexagonal prism. The quartz is cut with faces perpendicular to one of these three axes, with electrodes on the faces. The Curie brothers identified three cases. **Case 1** (the cylinder in Figure 2) was when pressure was applied *along the electrical axis* (x-axis) and charge was generated, and conversely the crystal expanded or contracted along the same axis when a voltage was applied. In **Case 2**, compression *along the length of the crystal* (the z-axis), no charge was generated along any electrical axis. This direction was also known as the optic axis, because no birefringence is observed along this direction. In **Case 3** (the rectangular plate in Figure 2) pressure in a direction *perpendicular to the electrical axis* (y-direction) caused charge to be generated on the faces perpendicular to the electrical axis, and conversely an applied voltage caused an expansion or contraction perpendicular to the electrical axis.

Figure 2 Diagram showing a hexagonal quartz crystal with an x-cut cylinder with its axis parallel with the electrical, x-axis, and a rectangular plate with its long axis perpendicular to the electrical axis and parallel with the y-axis



Röntgen's experiments.

Röntgen had been interested in the behaviour of quartz since 1874, when he had studied its thermal conductivity. Since 1878 he had carried out a number of experiments on the optical properties of quartz, and in particular on its birefringence and polarising ability. It was well known that double refraction in crystals could be altered by compression, so he was intrigued by the Curies' report which demonstrated a dimensional change in quartz caused by an applied voltage (the reverse piezoelectric effect). Might this also change its double refraction? The first of a trio of papers was sent in November 1882, and published in *Bericht der Oberheissischen Gesellschaft für Natur- und Heilkunde*. It was this set of three papers that Sir William Thompson arranged to be translated and republished in Phil Mag [4,5,6].

Figure 3. Quartz. The hexagonal form can be seen in the natural crystal, alongside a 5 cm diameter quartz sphere, or 'crystal ball'.

Röntgen did not have the ability to cut quartz in his own laboratory. In common with the Curie brothers, and Langevin later, he relied on a manufacturer of optical instruments to supply appropriate quartz plates for his experiments. Quartz is a naturally occurring crystal, found in igneous rocks throughout the world. At this time, the best clear quartz came from Brazil. Röntgen first obtained two rectangular parallelepipeds cut from a crystal of Brazilian quartz. He bought these from Steeg and Reuter, a company that had been formed in 1877 when Peter Reuter became co-owner of Wilhelm Steed's 'Optisches Institut' near Frankfurt. He explained in the first paper how he specified the size, 2x1.2x1.2 cm, where the longest dimension was perpendicular to the optic axis. He also specified that the cut should align with one of the Curies' polar axes but, 'owing to a misunderstanding on the part of the workman, little weight was attached to this condition'.

Luckily, he found that 'both pieces deviated but little' from his instructions. Wires were bonded between the crystals so that a voltage could be applied across the experimental zone from a Holtz machine. In this first experiment, he showed that the optical refraction altered with applied voltage.

Axes of missing piezoelectricity.

Röntgen then started to explore piezoelectricity. He first reproduced the Curies' compression experiments, observing the charge using a gold-leaf electroscope. At the end of his first paper, he developed the study beyond the three cases that the Curies had established. Instead of cutting quartz perpendicular to an electrical axis through the hexagonal *edges,* he ordered a 1.5 cm square plate, 2.5 mm thick, to be cut parallel with the hexagonal *faces* of the quartz: that is, in a plane rotated 30° around the longitudinal, optic, axis of the crystal (the z axis). He predicted that this orientation should generate no piezoelectric effect. This was indeed what he found in both piezo-electric experiments and a piezo-optic experiments. He called these three axes, equally spaced between the three electrical axes in the x-y plane, 'axes of missing piezoelectricity'.
Röntgen had now established that there were four axis in quartz along which charge was not generated during compression, one along the long (z) axis of the crystal and three more in the xy plane through the crystal. These axes lay between the three electrical axes. But what about any other combination of orientations? It would clearly be unfeasible to ask Reuter and Stern to make him a large number of quartz plates, each cut at a slightly different, specified angle through the crystal. His solution was to use a quartz cylinder and then, more importantly, a quartz sphere, a 'crystal ball', to examine the piezoelectric behaviour at other angles (Figure 3).

In his second paper [5] he described how he examined the variation of piezoelectric properties with angle. He first used a 3 cm diameter disc, cut with its diameter across the crystal in the x-y plane. Röntgen used a vice holding silver wire electrodes to clamp this disc across its diameter. On repeatedly rotating and clamping the cylinder he was able to confirm that the 'axes of missing piezoelectricity' were separated by 120°. He also noted a change of sign on moving across a zero.

The crystal ball experiment.

Röntgen then moved on to a more complicated experiment with a quartz sphere.
The formation of natural quartz into spheres had been known from antiquity. Pliny had stated that 'the best cautery for the human body is a ball of crystal, acted on by the sun'. The crystal ball is the iconic symbol of the fortune teller. It seems that standard quartz spheres could be obtained fairly readily, because Röntgen acquired at least two of them, and made no special mention of where they came from, in contrast to the clear statements he made about his source of the quartz plates.

In order to compress his sphere he adapted an old heavy microscope, with the barrel held vertically. He placed the 3 cm diameter sphere on the stage, supported by an earthed brass disc, with a central depression (Figure 4). If his experiment required the sphere to be insulated, the mount was made of a rubber disc supported by ebonite. He compressed the sphere by gently lowering the microscope barrel onto the sphere, and then adding a further 2 kg weight. Electrical charge created at any point on the sphere's surface was could be detected using a brass wire with an insulting handle, connected to a gold-leaf electroscope.

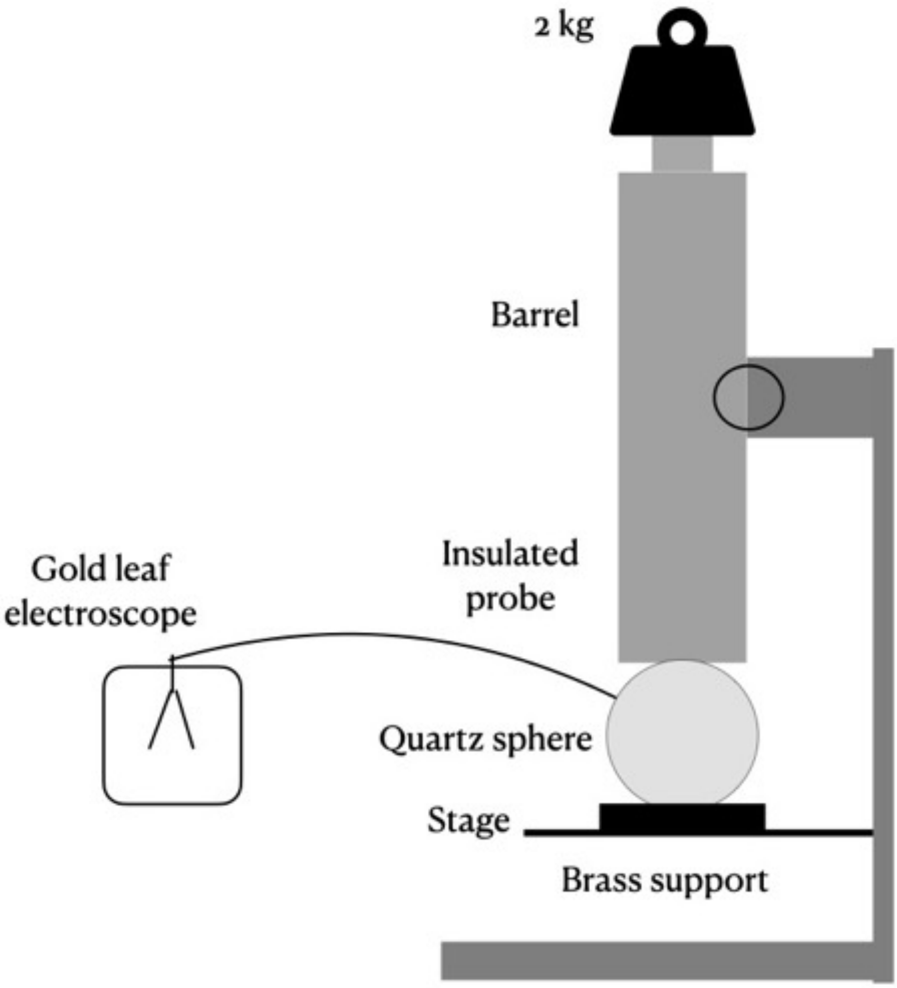


Figure 4. The adapted microscope used by Röntgen for his quartz sphere experiment

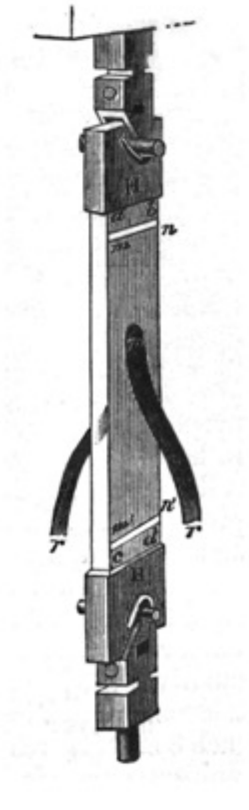
The first experiment located the crystalline orientation of the sphere. This was done by compressing the sphere in sequence along many directions, and in each case using the electric probe to identify and mark those regions on the sphere's surface that become only feebly charged, no matter how the sphere was squeezed. This identified the 'poles' in the neighbourhood of the ends of the optic axis, and planes of latitude, separated by 120°, containing the three axes of no piezoelectricity. He called these 'planes of no piezoelectricity'. Experimentally, the six angles between these three planes where not all precisely 60°, a deviation that he attributed to imperfections in the crystal. Such natural imperfections would concern Langevin and his colleagues in their later selection of crystals to be ultrasonic transducers.

He now had a view of the sphere as a globe, with poles and an equator. He designated it as being comprised of six piezoelectric segments, arranged somewhat like an orange. He then determined that alternate segments were charged with opposite polarity, three becoming charged positively with pressure, and three negatively. The greatest charge was always generated at the equator, and midway between the planes of no piezoelectricity, that is, on the electrical axes.

He then rotated the sphere, so that the optic axis was horizontal, and applied the force along one of the axes of no piezoelectricity. Charge was generated over the whole of the surface, positive in one hemisphere and negative in the other. It was maximum at the ends of the axis perpendicular to direction of pressure: in other words along an electric axis. Röntgen noted that this corresponded to the Curies' Case 3. Two hemispheres of opposite charge were generated, separated by a ring of no charge. He completed his examination of the sphere by exploring compression over a range of other directions, which divided the surface charge into a more complex segmentation.

Röntgen's second paper concluded with several further electro-optical experiments including one using a small quartz cylinder, which allowed him to visualise the optical effects of the six piezoelectric segments together. He concluded that it was through an understanding of the piezoelectric behaviour of quartz that an understanding of its optical behaviour could be reached. In the final, shortest, paper of this trio, he showed how his results could explain crystal electrification by heat conduction, or by heat radiation, or by pressure, as three examples that all resulted from strain within the crystal. In other words, that piezoelectricity was the fundamental property of the crystal causing all such electric effects [6]. In doing so, he brought these studies back to their start, Jacques Curie's examination of pyroelectricity. Röntgen showed how the changing stress in a crystal during heating or cooling could produce a charge distribution that differed from that caused by a steady, raised temperature. At almost the same time, Jacques Curie published a similar idea, giving credit to Röntgen's work.

Figure 5 Jacques and Pierre Curie's *quartz piézoélectrique*. It is cut from natural quartz so that the long axis and the faces, to which electrodes and leads r,r are attached, are both perpendicular to the electrical axis. The device is freely suspended and a weight, attached beneath, creates stress in the crystal that causes electric charge on its two faces.



From Röntgen to Langevin.

During the subsequent decade, a few of the senior European physicists considered how piezoelectricity might be explained theoretically. Notable amongst them was Sir William Thompson, and it was his initiative that brought Röntgen's experimental results to an English-speaking audience.

A decade after the original publications from the Curies and Röntgen, he presented a theoretical paper at the 63rd meeting of the British Association in Nottingham in September 1893. He was ennobled by then and his name, Lord Kelvin, was derived from the river that flowed past his office in Glasgow University. He also had been appointed as President of the Royal Society so, when he spoke, his presentations should have gained considerable attention. The text and illustrations were published in *Phil. Mag.* [7]. Lord Kelvin proposed that piezoelectric properties could be explained if the quartz was built up from an assembly of charged, regular hexagonal molecules. In his model the three positively charged silicon atoms are bonded to three negatively-charged oxygen doublets. He showed how strain in such a structure could result in surface charge. In his account, Lord Kelvin made particular reference to Röntgen's experimental results, although he cast doubt on Röntgen's '*Axen fehlender Piëzo-electricität'* , unable to predict any axes of zero piezoelectricity from his model.

The *quartz piézoélectrique*.

Kelvin's paper included an appendix, which was the first publicity outside France for a device called the *quartz piézoélectrique.* (Figure 5). He describes one example that had been made for him, in Paris 'under Mr Curie's direction'. It consists of a thin plate of quartz about 0.5 mm thick, with silvered faces 70 x 18 mm. It was cut from a quartz crystal with the electric axis perpendicular to the faces and so that a force could be applied perpendicular to that axis. This is the Curies' Case 3. Röntgen had also demonstrated in his experiment with the sphere how compression along a diameter perpendicular to an electric axis caused charge to be generated at the ends of a diameter at right angles to the compression. What delighted Kelvin particularly was the linear and quantitative relationship between force and charge, which could allow a known charge to be created by hanging a known weight on the device held in suspension, provided that the piezoelectric constant was known.

What later delighted Pierre Curie was that this *quartz piézoélectrique* was perfect for his radium experiments with Marie, enabling them to measure the ionisation from the increasing radioactivity as they progressively concentrated the radium ore. Nevertheless, as world-wide scientific interest in radioactivity proliferated, the Curie laboratory was the only one to report its use, others being satisfied with less sensitive means of measurement.

What happened next?

Röntgen moved to Würzburg in 1888. German physicists such as Voigt and Pockels puzzled over the theoretical aspects of piezoelectricity. But, by 1900, it was all over. Physicists refocused their attention towards resolving the new challenges posed by radioactivity, x-rays and quantum physics. Papers on piezoelectricity dried up. Jacques Curie had moved to Montpelier University where he became professor of Mineralogy. Pierre Curie was killed in a tragic accident in 1906. Text-books on mineralogy rarely mentioned piezo-electricity.

Röntgen himself was almost alone in retaining an interest in this obscure branch of physics during the first part of the twentieth century. After moving to Munich he assigned his young Russian assistant Abram Ioffe the task of studying electrical conductivity and stress in crystals. Ioffe returned to St Petersburg after completing his PhD in 1905. In 1911, Röntgen again returned to the challenge of measuring the piezoelectric constant of quartz, finally publishing his and Ioffe's results in 1913 and 1914. Otherwise, the study of piezoelectricity disappeared.

Ultrasound.

Wilhelm Röntgen did not seek the future by peering into his 'crystal ball'. He used his 'quartz sphere' to seek scientific truths, leaving the future to evolve naturally. But he lived long enough to witness the first years of ultrasonic detection, when x-cut quartz transducers emerged as the enabling technology on which all later developments in ultrasound were built. The French physicist Paul Langevin had been working with the French Navy from 1915 to develop equipment to detect

U-boats using ultrasonic echoes. There were technical problems with his mica transmitters and carbon detectors. In February 1917 he started to explore whether the piezoelectric properties of quartz, which the Curies and Röntgen had examined under conditions of *static* stress and charge, might be retained with little loss when the crystal was *vibrating* at up to one hundred thousand cycles per second. He rejected the orientation of the cut used by the Curies' *quartz piézoélectrique*. Instead, he returned to the Curies' 'Case 1', in which the direction of stress was aligned with the electrical axis. His success in using this cut for the reception of ultrasound quickly led to a similar and more dramatic success when he caused this x-cut quartz to vibrate at 100 kHz, generating a beam of ultrasound. This story has been told in more detail elsewhere [8]**.** Langevin's subsequent recognition as the 'the originator of the modern science and art of ultrasonics' [9] was built not only on the original pioneering studies of Jacques and Pierre Curie, but also on the careful experimental consolidation by Wilhelm Röntgen and his brilliant and imaginative use of a 'crystal ball'.

References.

[1] Dawson P. Röntgen's other experiment. *Br J Radiol* 1997;70:809-816.

[2] Katzir S. *The beginnings of piezoelectricity*. Boston studies in the philosophy of science 246. Springer 2006.

[3] Duck F. 'The Electrical Expansion of Quartz' by Jacques and Pierre Curie. *Ultrasound* 2009;17:197-203.

[4] Röntgen WC. On the change in the double refraction of quartz produced by electrical forces. *Phil Mag Ser 5* 1883;15:132-135.

[5] Röntgen WC. On the change in the double refraction of quartz produced by electrical force. *Phil Mag Ser 5* 1883;16:96-109.

[6] Röntgen WC. On the thermoelectric, actinoelectric and piezoelectric properties of quartz. *Phil Mag Ser 5* 1883;16:194-197.

[7] Kelvin, Lord. On the piezo-electric property of quartz. *Phil Mag Ser 5* 1893;36:331-342.

[8] Duck F. Ultrasound –the first fifty years. *Med Phys Int J* Special Issue, History of Medical Physics 5. 2020:470-498. http://www.mpijournal.org/pdf/2021-SI-05/MPI-2021-SI-05.pdf

[9] Cady WG. *Piezoelectricity*. New York, McGraw–Hill. 1946.

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“DIY” Catheters.

By Adrian Thomas

(Note: An earlier version of this article appeared in the HMES Bulletin, No 36, Sept 2021 30-32. And is partly reproduced with permission).

We are now so used to having a wide variety of catheters all prepared in sterile packaging that it’s difficult to imagine a previous generation who had to shape their own catheters for selective arterial catheterization. In 1962 David Sutton (1917-2002), a radiologist from St. Mary’s Hospital in London, reviewed the current state of arteriography in his highly influential book Arteriography [2]. When Sutton was a senior registrar at the Middlesex Hospital he developed his techniques for peripheral and placental angiography. Placental angiography was needed to identify the location of the placenta in this period prior to ultrasound. In his influential book Sutton described the insertion of a catheter into an artery over a wire using Seldinger’s Technique, and bending the catheter into any required shape using hot water. A curved catheter was required for selective arteriography.

In 1963 William ‘Bill’ Cook (1931-2011), with his wife Gale, started what became Cook Group in a spare bedroom in their apartment [3]. Cook Medical are now a major supplier of sterilized and packaged wires and catheters for radiological intervention. In the November of 1962 Bill Cook and the pioneer interventional radiologist Charles Dotter (1920-1985) met for the first time at the Cook’s rather low budget booth at the convention of the Radiological Society of North America in Chicago. Cook’s company was then only four months old, and on the stand Cook had wire guides, needles, a blowtorch, and was making catheters in front of his fascinated visitors. Dotter asked to borrow Cook’s blowtorch for the night, and he returned the next day with ten perfectly made catheters. Cook recounted that he sold the catheters for $10 each and that his was enough to pay for the booth! Bill Cook and Charles Dotter developed a lifelong friendship, which was to prove mutually beneficial. Following a discussion about catheter and wire guide manufacture Cook visited Dotter in Oregon. Cook could not afford the air fare and so Dotter paid his expenses. Dotter had his own laboratory where technicians made their own wire guides. Dotter was also producing his own catheters using Cook’s Teflon tubing. It cannot be emphasized too much that his was long before the contemporary period with prepackaged and preformed sterile catheters. The catheters were supplied unsterile as a long loop and could be cut and formed as desired. There were a variety of recommended shapes for angiography for selective studies of particular arteries. The fabrication technique was time consuming and required skill and patience.

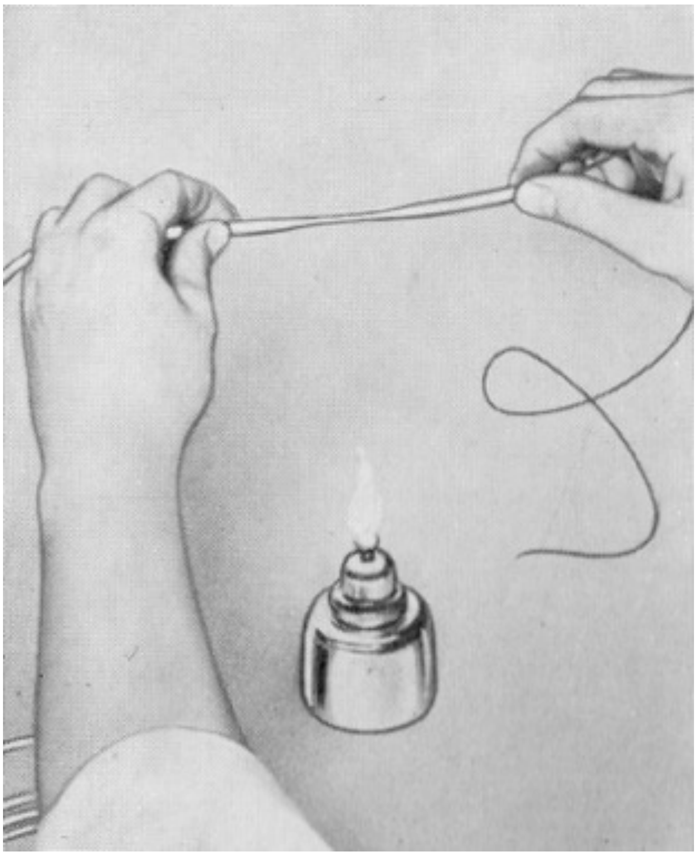
The stages were:

1. The disposable Öldman-Ledin opaque catheter was supplied in four sizes, and in 17 feet (5.2m) lengths (Fig.1). The sizes were colour coded for identification. The catheter was not to be cut to the required length until the catheter tip had been prepared. If a completely straight length was desired then a section was held in steam from boiling water.

[2] Sutton, D. 1962. *Arteriography.* E&S Livingstone.
[3] Hammel, B. 2008. *The Bill Cook Story, Ready, Fire, Aim!* Indiana University Press.

1. Öldman-Ledin opaque catheter (collection of the author).

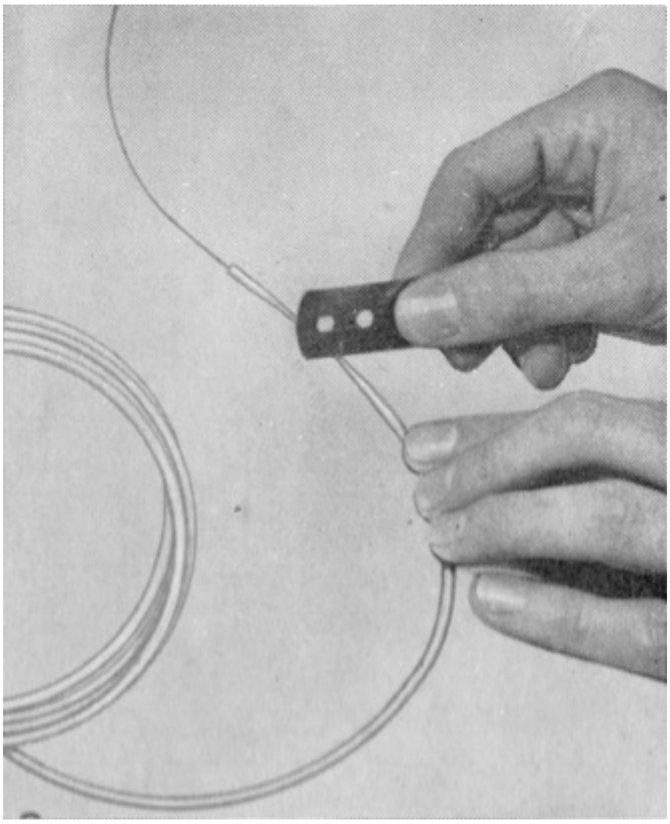
2. Tip forming (Fig.2). A forming wire was placed in the catheter, the catheter was warmed over an alcohol flame, and the catheter was pulled from both ends. A narrowed section was produced corresponding to the diameter of the guide wire.



2. Tip forming.

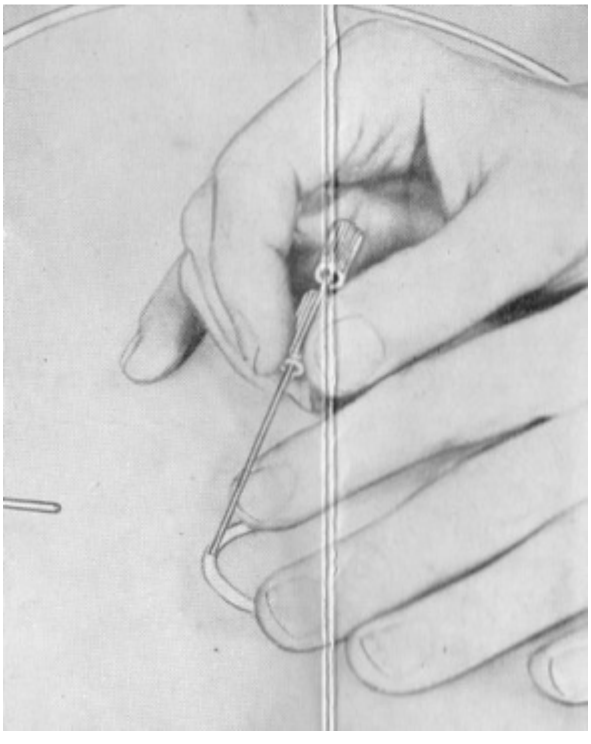
3. Tip finishing (Fig.3). The tip was tapered and cut with a razor blade with the guide wire still in place. The end was then rounded with emery polishing paper.

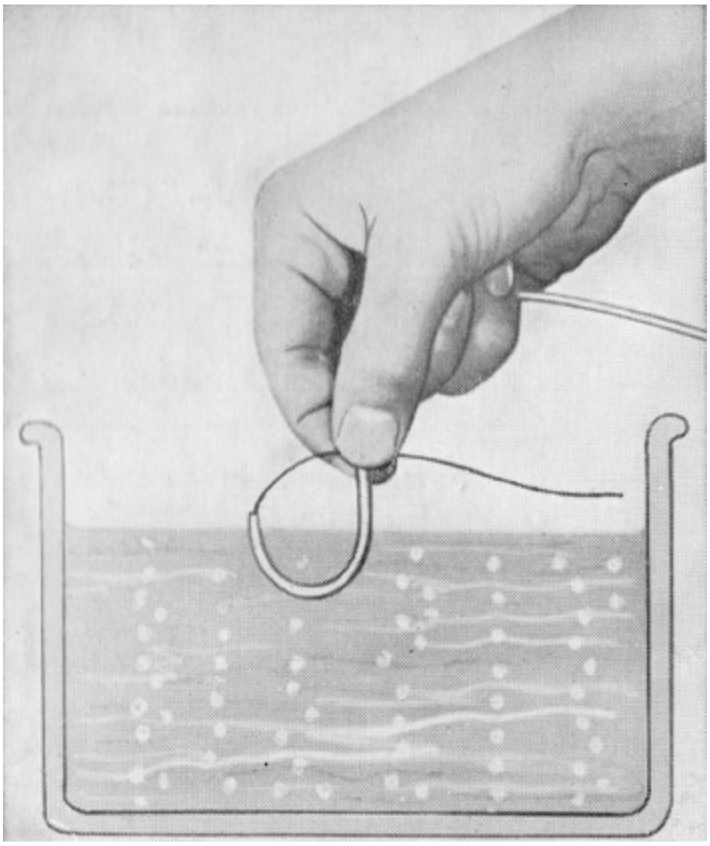
Fig. 3. Tip. Finishing.



4. Side hole forming (Fig.4). This was achieved using a sharpened hole punch cannula. The punch was gently rolled until the wall was punctured. If the central hole was not required it could be closed using the alcohol flame.

Fig. 4. Side Hole Forming.



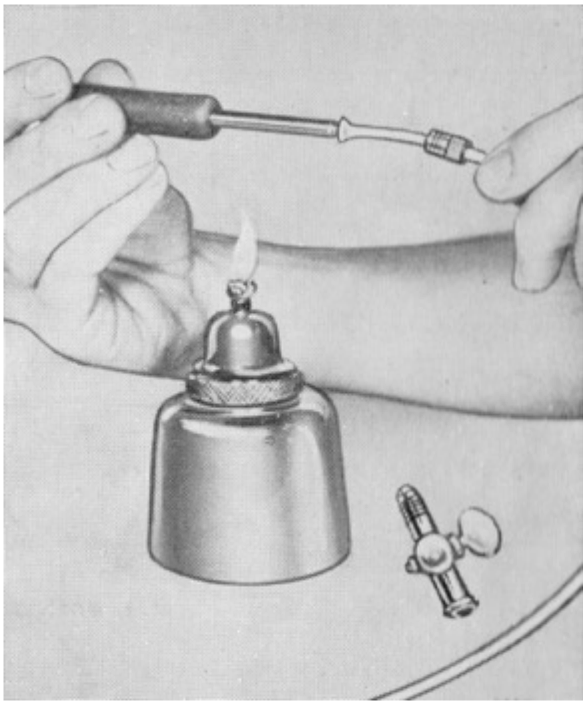


5. Shaping (Fig.5). This was performed by inserting a pre-formed wire and placing the tube in hot water. The catheter was than quenched for about one minute in cold running water. The formed catheter would not change shape at body temperature.

Fig. 5. Shaping.

6. Flaring (Fig.6). The catheter was cut to a pre-selected length. The tubing would automatically flare when placed near an alcohol lamp. Alternatively, a flanging tool might be used. The tip of the flanging tool would be slightly heated.

6. Flaring the catheter.



7. Sterilizing. The tubing was filled with a cold sterilizing solution and also fully immersed. Gas sterilization could also be used. The tubing was not to be autoclaved. Following use the catheter was to be discarded to avoid the risk of re-infection, however the metal catheter adaptor could be boiled and reused.

8. A completed catheter (Fig.7), in this case made by William Cook. An early French-8 gauge 'pig-tail' catheter with a metal adaptor, and used for aortography.

Fig.7. Completed catheter. (collection of the author).

The company Kifa of Sweden illustrated recommended different catheter shapes (Fig.8), and these were illustrated by David Sutton in his book and were also shown on the packet containing the catheter. The whole process of angiography during this period was difficult and time consuming. Skills were required to perform the procedures; however, skills were also required to make the catheters. In the 1960s the numbers of angiograms were relatively small, and the technique was mainly used for diagnostic procedures.

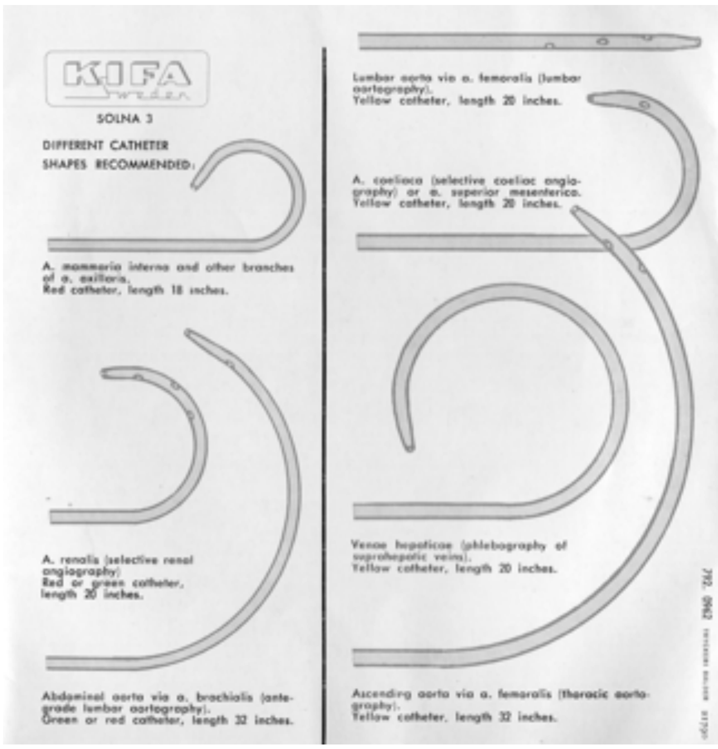


Fig. 8. Types of catheter.

Angiography as a diagnostic procedure has now been replaced by non-invasive techniques such as ultrasound, however the growth of interventional radiology has confirmed the essential role of the manufactures of sterile and packaged needles, guidewires and a complex variety of catheters. It has been the fruitful cooperation between radiologists and the catheter and device manufacturing companies that has facilitated the modern speciality that is interventional radiology.

Note: Thank you to Kifa for permission to reprint their illustrations from the card that accompanied the catheter in the collection of the author.

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