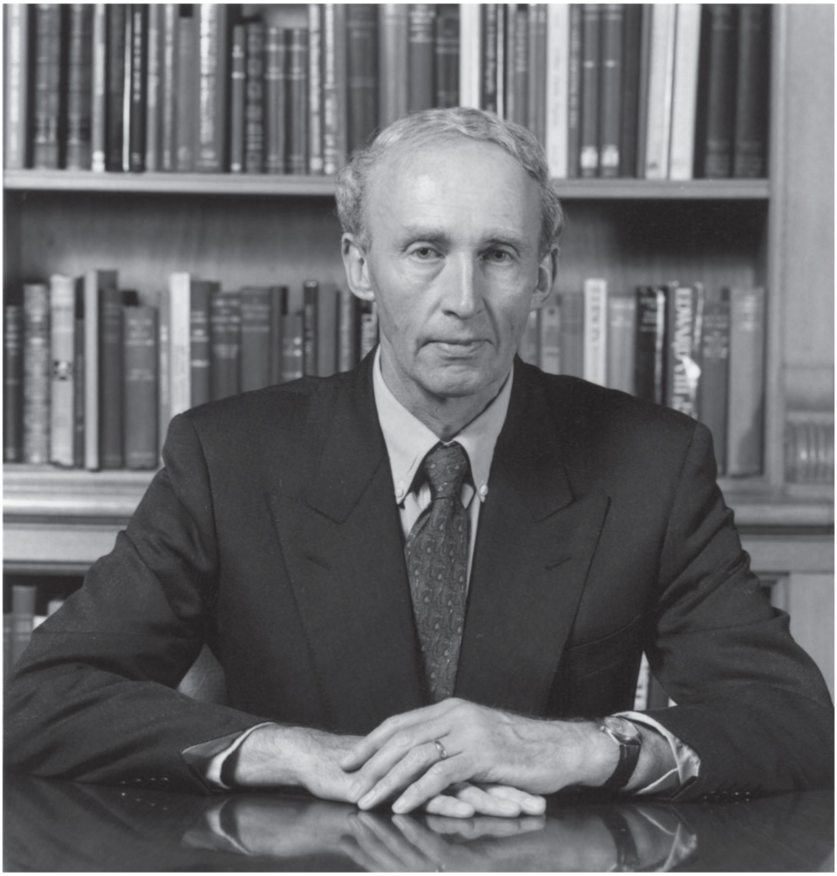
# JOHN EDWIN FIELD

20 September 1936 — 21 October 2020



John Field

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20 September 1936 — 21 October 2020

Elected FRS 1994

BY STEPHEN M. WALLEY[1,*], WILLIAM G. PROUD[2] AND
TIMOTHY G. LEIGHTON FRS[3]

[1]*Cavendish Laboratory, University of Cambridge, Cambridge, CB3 0HE, UK*
[2]*Institute of Shock Physics, Imperial College London, London SW7 2AZ, UK*
[3]*Institute of Sound and Vibration Research, University of Southampton, Southampton SO17 1BJ, UK*

John Field was a brilliant experimental physicist who made major contributions to the physics and chemistry of solids. His research interests spanned a very wide range of topics, most of them involving energetic phenomena. These areas included the strength properties of solids, fracture growth, impact and erosion phenomena, shock physics, reactivity of solids, explosive initiation, lasers, acoustics and medical physics. Within the Physics and Chemistry of Solids Group in the Cavendish Laboratory, he developed the best-equipped high-speed camera facility in any university in Europe, including seven that achieved frame rates in excess of $10^6$ frames per second. In addition to the cameras, extensive use was made of ultrasonics, optical and electron microscopy, mass spectroscopy and thermal techniques. He played an important national role in advising the Ministry of Defence on a wide range of topics in energetic phenomena and materials science, which led to practical engineering solutions. He was an outstanding supervisor of doctoral students, who remember him fondly.

## EARLY AND UNDERGRADUATE YEARS

John Field was born on 20 September 1936 in Stourbridge, Worcester, to William Edwin Field, a butcher, and his wife Madge Field, née Normansell. His younger brother, David Henry Field, was born after the Second World War. Neither of John's parents had a scientific background,

* smw14ster@googlemail.com


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but his mother's father, Thomas Henry Normansell, was an engineer and inventor; in 1920, he and his brother Ernest submitted a patent application entitled 'Improvements in or relating to Safety Signalling Apparatus for use on Motor-cars and other Motor-driven Road Vehicles', but they could not afford to maintain payment for the patent fees. John's parents were always encouraging, but could not help or advise on matters related to a scientific career. Their neighbours, the Lees, however, had two sons who were a few years older than John and they studied physics. The elder, Roland Lee, won a scholarship to St John's College, Cambridge, and eventually became director of the Ministry of Defence (MOD) Laboratory (then the Royal Signals and Radar Establishment) at Malvern, while his younger brother, Donald Lee, studied physics at Birmingham and then worked at Harwell. As John put it, these friends 'certainly "nudged" me in the direction of physics' (personal communication).

John began his primary education at Wollaston Primary School (1941–1942) and then continued at Hills Road Primary School (1942–1947). For his secondary school education, he attended King Edward VI Grammar School in Stourbridge, which he described as a 'good Grammar School', from 1947 to 1955. He loved cricket, was a member of the school athletic team and supported the West Bromwich Albion football club. The school provided a good foundation for entrance to University College, London, where Harrie Massey FRS was an inspiring and dynamic head of the physics department. John studied at the college from 1955 to 1958, obtaining a first class honours degree in physics in his final year.

## A Cambridge career

With this success behind him, John began a PhD at the Cavendish Laboratory, University of Cambridge, in the Physics and Chemistry of Solids Group under the supervision of its head, Philip Bowden FRS. Cambridge and the Physics and Chemistry of Solids Group were to be John's base for the rest of his career. As he wrote later,

> Philip Bowden must rate as the most dominating influence on my career. He enjoyed his science, both basic and applied, and his contacts with Industry and Government Laboratories.

## The Physics and Chemistry of Solids Group

In 1927, Bowden had come to Cambridge from Tasmania, Australia, supported by an 1851 Senior Research Studentship to study with Eric Rideal (FRS 1930), then a lecturer in the Physical Chemistry Department. The department was located next door to the Cavendish Laboratory in Free School Lane. Following the award of his PhD in 1929, Bowden progressed rapidly up the academic ladder, becoming the Humphrey Owen Jones lecturer in 1937. His interests evolved from electrochemistry to various aspects of friction during the 1930s. There followed a series of research investigations on many different aspects of friction and lubrication: kinetic friction, frictional 'hot-spots', frictional heating and surface melting, adhesion of clean surfaces and the measurement of the real area of contact between stationary and sliding surfaces. He also noted that, even at relatively small rates of sliding friction, very high temperature flashes could occur, possibly resulting in local melting although the bulk of the material remained cool. This was to inform his subsequent studies of the role of hot-spots in detonation, and these were all areas in which John was subsequently to take a strong interest.

The research on friction and lubrication attracted the attention of oil companies and other industrial organizations in the UK, The Netherlands and the USA, and resulted in the formation of a small research unit dedicated to studies of wear and lubrication led by Bowden. With the approach of war, the Air Ministry, the Fuel Research Board and the War Office showed increasing interest in Bowden's activities, resulting in valuable contracts for the support of the research programme. Bowden was in Australia when World War II broke out, but returned to Cambridge after it was over. He had already written a prophetic memorandum entitled 'A study of the physical and chemical phenomena associated with rubbing and with the impact of solids' in March 1944, in which he laid out his vision for his post-war activities in Cambridge. He also concluded that (Tabor 1969):

> War experience has shown clearly that, in pre-War days the academic and practical research were too widely separated and suggests that, in future, contact between the two should be maintained. The action of joint committees and frequent meetings and discussion can do something towards this. It is obvious that one method of making this contact more real is by the interchange of personnel, and it is suggested that in this case arrangements be made for certain members of the Service and Industry Research establishments to come to Cambridge and work for a time, normally for not less than a year, and conversely for members of the Cambridge laboratory to go into the Research establishments.

In 1945, he set about implementing this programme from his base in the Department of Physical Chemistry, where he was promoted to a readership in 1946. He was joined by a number of his colleagues from the CSIR Laboratory in Australia, including Jeofry Courtney-Pratt, a pioneer of high-speed photography, David Tabor (FRS 1963), an expert on friction, and Abe Yoffe, whose expertise was in the initiation of explosions. In the aftermath of the War, Bowden obtained the resources to start his programme with funds from the Ministry of Supply and also the Department of Industrial Research, where Edward Appleton FRS was executive secretary. The group was to rely upon industrial and defence funding, a pattern that was maintained throughout its subsequent history. Through his many industrial and defence contacts, the scope of the programme expanded dramatically. Bowden named the group The Physics and Chemistry of Rubbing Solids.

The turning point came in 1956 when the chemistry department began its move into new buildings in Lensfield Road. There had already been strong collaborations between the group and members of the Cavendish Laboratory. The research interests of the group were remarkably close to those of Nevill Mott FRS, the Cavendish Professor and head of the Cavendish Laboratory, and often closer to physics than to chemistry. Bowden and Mott agreed that the research of the group would be best served by being transferred to the Cavendish Laboratory and, after what Mott described as 'a good deal of fixing', their aim was achieved. The title of the group eventually settled on the Physics and Chemistry of Solids (PCS) and brought to the Cavendish all the distinctive areas of research that had been fostered by Bowden and his colleagues. In 1966, just two years before his death, Bowden was promoted to an *ad hominem* professorship. Until the Cavendish Laboratory moved to new buildings on the west Cambridge site, PCS was located in buildings on Free School Lane that had previously housed the Department of Physical Chemistry.

Figure 1. John and Ineke in Lausanne. (Online version in colour.)

## John in Cambridge

Bowden had created a research group that was strongly multidisciplinary in a contemporary sense. Upon Bowden's death in 1968, David Tabor became the head of the PCS Group until he retired in 1981. He was succeeded as head by Abe Yoffe and then, on Yoffe's retirement in 1987, by John, by which time PCS was 160 strong. Other important early influences on John's scientific outlook included Alan Cottrell FRS, mainly through his lectures and books on materials science, and Charles Frank FRS, who taught him the simple, but useful, lesson not to be shy about saying that you do not understand something. John also remarked,

> It would be difficult to be in the Cavendish and not be impressed, and influenced, by G.I. Taylor, Nevill Mott and Brian Pippard. I remember thinking as a PhD student that most scientific problems could be solved by getting Taylor, Mott, Pippard, Cottrell and Frank together. (personal communication)

John began his doctoral studies in 1958 and was awarded his PhD in 1962 for his dissertation entitled 'The deformation and fracture of brittle solids'. One technique that John used in this study was high-speed liquid impact (1), and the damage produced by such impacts remained one of John's research interests throughout his career.

While he was a research student, he met Ineke Tjan, who was working in the university library and was of Dutch nationality (figure 1). They married in Cambridge in 1963 and had three children: two boys, Andrew and Richard, and a daughter, Lise. Andrew is a production designer and Richard works in horticulture in France. Lise works in Queens' College library in Cambridge. There are five grandchildren (figure 2).

Figure 2. John, Ineke and family celebrating Christmas in December 2015. Their daughter Lise is in the front row at the left. Richard is second left and Andrew on the right at the back in the picture. (Online version in colour.)

After completing his doctoral studies in 1961, John won an Owens-Illinois Research Fellowship sponsored by the American glass manufacturer of that name, enabling him to carry on his studies of fracture and liquid impact. In 1964 he became a research fellow and college lecturer at Magdalene College, which was to remain his college for the rest of his life. He made major contributions to Magdalene as joint director of studies in natural sciences from 1973 to 1987, tutor for graduate students 1974–1987 and acting librarian whenever the college librarian was on leave. He always found time to help students in the college with their problems. He and Ineke were regularly present at drinks before the weekly dinners for graduate students. He offered wise counsel to his colleagues, and would articulate the humorous side of a situation with a gentle smile just when that was needed. His enthusiasm for cross-country running extended to his running for the college. John joined the academic staff of the Cavendish Laboratory in 1966 as a university demonstrator (assistant lecturer), at the same time becoming an official fellow of Magdalene College. As a member of the teaching staff, when Bowden died in 1968, he took over the supervision of two of Bowden's PhD students: Graham Coley (8) and Munawar Chaudhri, who studied, respectively, liquid and solid primary explosives. John was promoted to lecturer in 1971, at the same time taking over as head of the Fracture and High Speed Photography Group within PCS until 1990, by which time this sub-group consisted of 33 members. He was promoted to reader in applied physics in 1990 and to professor of applied physics in 1994. This was a period of remarkable productivity, as described in more detail below. In his own words of 1993, he wrote:

> [My] research fields to date include strength properties of solids, fracture growth, impact and erosion phenomena, shock physics, reactivity of solids, explosive initiation, lasers, acoustics and medical physics. I have built up what is probably the best-equipped high-speed camera facility in any University in Europe—10 high-speed cameras of which seven can achieve framing rates in excess of $10^6$ frames per second. In addition to the cameras, extensive use is made of ultrasonics, optical and electron microscopy, mass spectroscopy, and thermal techniques (Differential Scanning Calorimetry and Thermal Gravimetric Analysis). (personal communication)

During the period from 1987 onwards, while John was head of PCS, it spawned two major new groups in the Cavendish: the Optoelectronics Group, led by Richard Friend (FRS 1993), and the Tabor Laboratory, under the leadership of Athene Donald (FRS 1999). The latter group investigated soft condensed matter physics and subsequently the physics of biology, with the strong support of Sam Edwards FRS, the then head of the Cavendish.

John's authority, expertise and innovation in these fields were recognized by the award of an OBE in 1987 and by his election to Fellowship of the Royal Society in 1994, the citation stating:

> Distinguished experimentalist working in areas which overlap physics, chemistry, engineering and materials science. Dr Field has built up the best equipped University Laboratory in Europe for high-speed photography. He has helped to develop the latest cameras which now cover a range from a few frames a second to 20 million a second. Combining this facility for direct observation with ingenious and original techniques he has resolved many problems of impact, fracture and erosion including the stress-field at the tip of fast-moving cracks. He has greatly extended our understanding of explosive reactions, rock mechanics and the failure of diamond films. Dr Field's work which covers a wide range of practical topics has an important influence on engineering design as well as being good physics. He is widely regarded internationally and his advice and help are widely sought by Government establishments and Industrial Laboratories both in this country and abroad.

In 1998, John was appointed deputy head of the Cavendish Laboratory by its then head, Malcolm Longair (FRS 2004). He performed this role in an exemplary fashion, including taking responsibility for a number of tricky issues that he resolved calmly and efficiently.

From his days as a research student, John was active in the Cambridge Philosophical Society, a scientific society founded in 1819 that promotes activities across the sciences and humanities—it was granted a royal charter by King William IV in 1832. John became physical secretary in 1962, a role he carried out until 1991.

## Research scientific style

Research students in John's group were expected to design and build their own apparatus with the help of the expert staff of the PCS workshop. His success in attracting money from government and industry ensured that there was no lack of funding.

John was skilled in persuading good undergraduates to carry out PhDs with him on apparently unglamourous, but important, projects. As an example, following a brief chat with John, Ian Hutchings was persuaded to change tack from particle physics to solid particle erosion. At that time, little attention was paid to health and safety matters; Hutchings recalls how, within days of starting research, he was firing small solid particles at surfaces by spalling them off thin copper shims positioned above an electrically-initiated detonator that was fired by using a screwdriver to short circuit two wires connecting the detonator to the mains.

In the 1960s, newcomers were impressed by the lack of hierarchy in the group, exemplified by the willingness of all group members to collaborate with one another, except on the usual thorny issue of the location and size of offices—like all groups, the laboratory was seriously overcrowded until the move to west Cambridge in the early 1970s.

John always communicated his students' best work to the Royal Society for publication. Over the course of his career, he was the co-author of 32 papers in *Proceedings of the Royal Society A* and nine in *Philosophical Transactions Series A*. He also encouraged them to develop contacts in the UK and internationally, both within universities and within industry. Students were expected to attend one international conference and at least one in the UK each year, a legacy of Bowden's approach. Over the course of his career, John supervised 84 research students. A list of the students John supervised, along with their areas of research, can be found in the electronic supplementary material.

## Research topics

This section provides a more detailed account of the research activities carried out by John, his colleagues and his graduate students.

### *High-speed photography*

During the 1950s, Bowden took on John Brunton as a research student to study the damage produced by the impact of raindrops on aircraft and missiles. To do this, they used a Beckman and Whitley 189 rotating mirror camera that had been acquired by Bowden from DuPont (Bowden & Brunton 1961). John continued this work (4)*, and also studied the effects of stress waves on fracture (figure 3) (6).

The use of highly resolved high-speed photography in impact experiments showed the mechanisms of crack initiation and the development of shear planes underneath an impact, which correlated with Hertzian cone formation. In addition, the experiments demonstrated the supersonic velocity of the contact point between the liquid and glass surface as a core mechanism in this process. The research led to the development of the automatic liquid impact apparatus, which was sold to a variety of interested parties. These techniques are now being deployed in the understanding of the reliability of wind turbines.

Jon Huntley was one of the first students in John's group to use microcomputers to analyse data—full-field strain measurements of materials in three-dimensions generate a large amount of data. In 1983, the BBC Micro had just appeared, the brain-child of Hermann Hauser (FRS 2012), one of John's former PhD students, and colleagues in Acorn Computers. John initially was of the opinion that integrating a computer into a test rig risked introducing months of delays, but eventually he was persuaded and was then very supportive.

For the high-speed work, John's suggestion was to use a rotating mirror camera and a pulsed ruby laser. This was eventually successful (34) (Huntley 1994). Huntley also developed

* Numbers in this form refer to the bibliography at the end of the text.

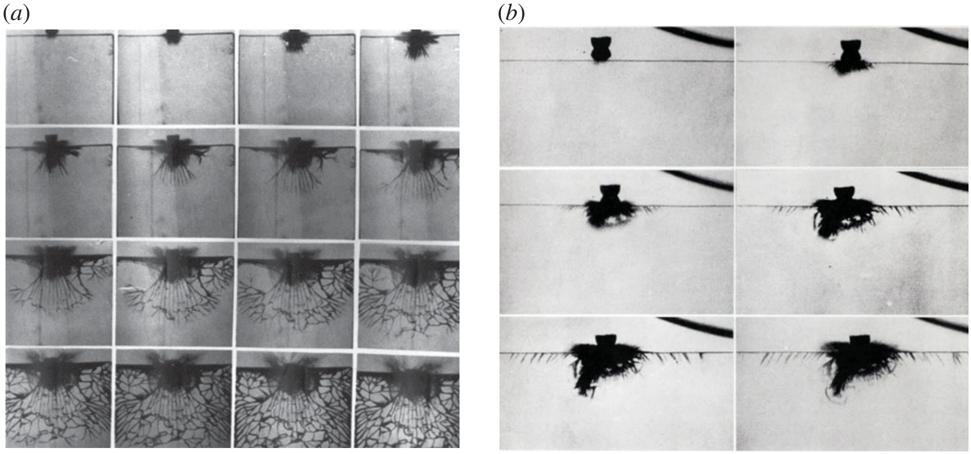



Figure 3. (*a*) High-speed photographic sequence of propagation of fracture in a plate of toughened glass; interframe time 2.0 µs. From (6), with permission from SPIE. (*b*) Initiation of fractures by a surface wave propagating along the top edge of a glass plate; interframe time 1.94 µs. From (2), with permission from the Royal Society.

a high-resolution moiré technique that, when combined with high-speed photography, allowed displacement maps of dynamic events to be plotted with sub-micron resolution at microsecond time intervals (figure 4). This technique found subsequent application in validating the theoretical solution for the acceleration field around a crack tip due to stress wave loading. The experiments and numerical integrations were carried out by Martin Whitworth, the analytical solution being developed by Ben Freund of Brown University, USA, a leading theoretician in the field of dynamic fracture.

### *Strength of materials*

One of John's strengths was his ability to devise simple, highly instrumented experiments to explore dynamic material behaviour. Although John's papers describe experiments of elegant simplicity, the simplicity is deceptive. The choice of experiment itself requires creativity of a high order to see how results of wide significance can be made credible and to be able to support the usually expensive and labour-intensive apparatus required. John's ability to marshal the resources and recruit the first-rate people required continued the great tradition of British experimental physics going back through Bowden and Tabor to G. I. Taylor to Thomas Young.

In the 1960s, John began a long-standing collaboration with De Beers into the mechanical properties of diamond. His initial research was into its fracture properties (5), but later this extended to friction and polishing (21, 26), erosion (33) and response to shock waves (46). The ancient and profitable technique of polishing diamond is a remarkable example. It is usually the case that a material can be polished only by finely dispersed grit of a harder material, often diamond. How, then, can diamond, the hardest known substance, polish itself? The answer lies in the anisotropy of the crystals, which enables certain surfaces to polish others, at the same time displacing what had been called a 'waxy' residue. With Tabor, John proposed that this was most likely amorphous carbon. Frank van Bouwelen was set the task

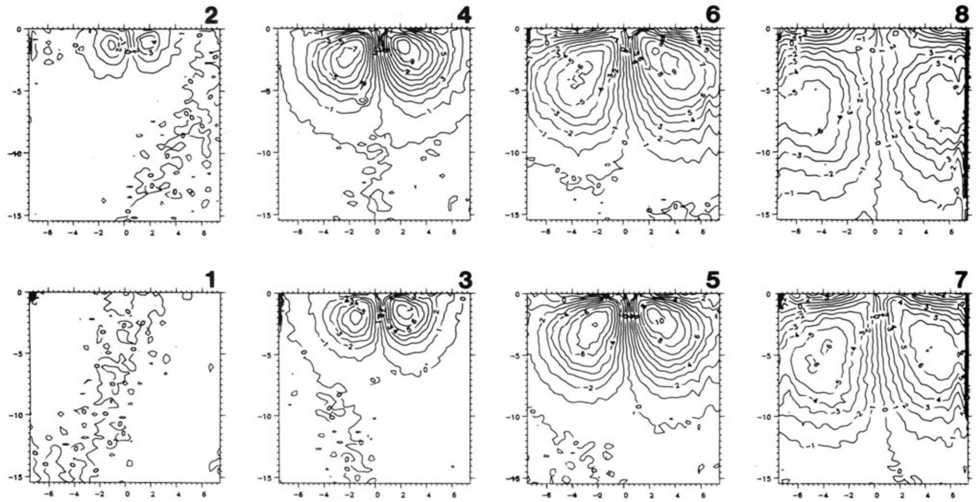


Figure 4. Maps of the horizontal displacement produced by the impact of a 2 mm diameter steel ball at 115 m s$^{-1}$ on a block of PMMA. Interframe time 0.95 µs. Each contour line in these plots differs by 1 µm from its neighbour. From (27), with permission from SPIE.

of using scanning transmission electron microscopy and electron energy loss spectroscopy to investigate the problem, essentially verifying the amorphous carbon hypothesis—it also revealed an extremely interesting process of a stress-induced transformation of diamond to graphite, associated with crystalline anisotropy, which can potentially resolve the paradox of diamond polishing (43). The paper ends with a compelling explanation of how the grit on the polishing wheel reacts with trial stones to select the harder particles capable then of polishing softer crystallographic surfaces on more valuable ones to fabricate dazzling gemstones. John's role in this work was typical of his research style: he suggested the topic, attracted an extremely capable student and, with the aid of practical expertise provided by his direct contact with diamond polishers, kept his discerning eye on the main problem.

For many years John organized the annual diamond conference, which moved between Cambridge, Oxford, Reading, Warwick and Royal Holloway. It was always held about the time of the annual Wimbledon tennis tournament, which the executives of De Beers wished to attend. For the benefit of newcomers to the field, John wrote a review paper (48) and edited two books on the properties of diamond (14 , 29).

In the early 1980s the UK MOD research establishments realized there was a need to understand the dynamic properties of both inert and energetic materials. They turned to John, who persuaded David Gorham to stay on as a post-doc to develop a miniaturized (3 mm diameter) direct-impact Hopkinson bar. Developed by Bertram Hopkinson FRS, professor of engineering at Cambridge, the Hopkinson bar enabled, for the first time, the experimental determination of the shapes of mechanical impulses generated by impact or explosions. During the Second World War, G. I. Taylor and E. Volterra realized that two Hopkinson bars placed back-to-back and sandwiching a specimen could be used to measure the dynamic strength of materials (Walley 2020). Since the 1970s, the technique has grown to become the most widespread method of obtaining this information. John realized that a small bar system was

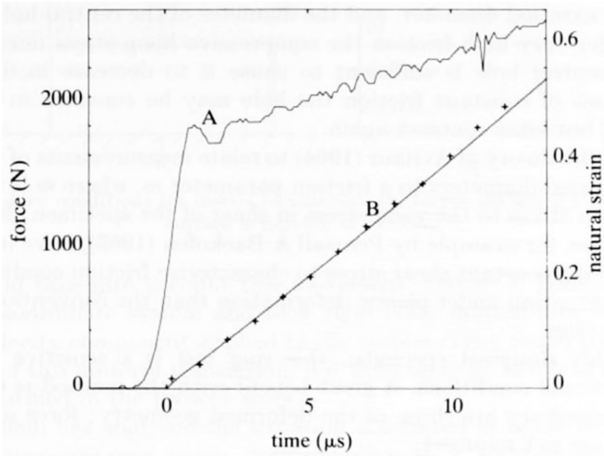



Figure 5. Experimental data for a tungsten–nickel–iron alloy. The '+' signs indicate the strain measured using high-speed photography. These values can be compared with curve 'B' calculated assuming conservation of specimen volume. From (32), with permission from the Royal Society.

needed in order to measure stress–strain curves at the very high strain rates of interest to the MOD. Miniaturization enables strain rates of $10^4$–$10^5$ $s^{-1}$ to be accessed, an order of magnitude greater than those accessible in conventional split Hopkinson bars ($10^3$ $s^{-1}$), while direct impact allows these very high strain rates to be reached very quickly (1–2 μs) (figure 5).

Subsequently Peter Pope, Stephen Walley, Simon Mentha, Nick Safford and Clive Siviour worked with John to develop split Hopkinson pressure bar systems that can provide accurate measurements of the high strain rate mechanical properties of metals, polymers, granular materials and energetic materials (28, 31, 32, 43). This is vital for the development of physically-based constitutive models for materials that can be used with confidence in numerical simulations.

Small bars permitted the use of smaller samples, making the safe testing of energetic materials routine. This enabled the validation of the modern materials science-based constitutive models and confidence in their use in wider applications. Lewis Lea was able to use even smaller bars to study phonon drag in face-centred cubic metals, generating data in support of Brown's theory on time-dependent slip, Lea also proposing an alternative credible mechanism.

More recently members of the PCS Group have revived the direct-impact technique and have achieved strain rates of $10^5$ $s^{-1}$ that Gorham and John were aiming for in the 1980s. The reason this is possible now and not then is that optical velocimetry methods are available that did not exist 40 years ago (Avinadav *et al.* 2011; Casem *et al.* 2012; Lea & Jardine 2016).

### *Energetic materials*

After Coley and Chaudhri had graduated, John's interest in energetic materials extended into solid secondary explosives through his supervision of Stephen Heavens (10). The classic high-speed sequence that Heavens obtained (figure 6) shows the initiation and growth of three hot-spots consuming a sample of secondary explosive (PETN) powder. Such studies

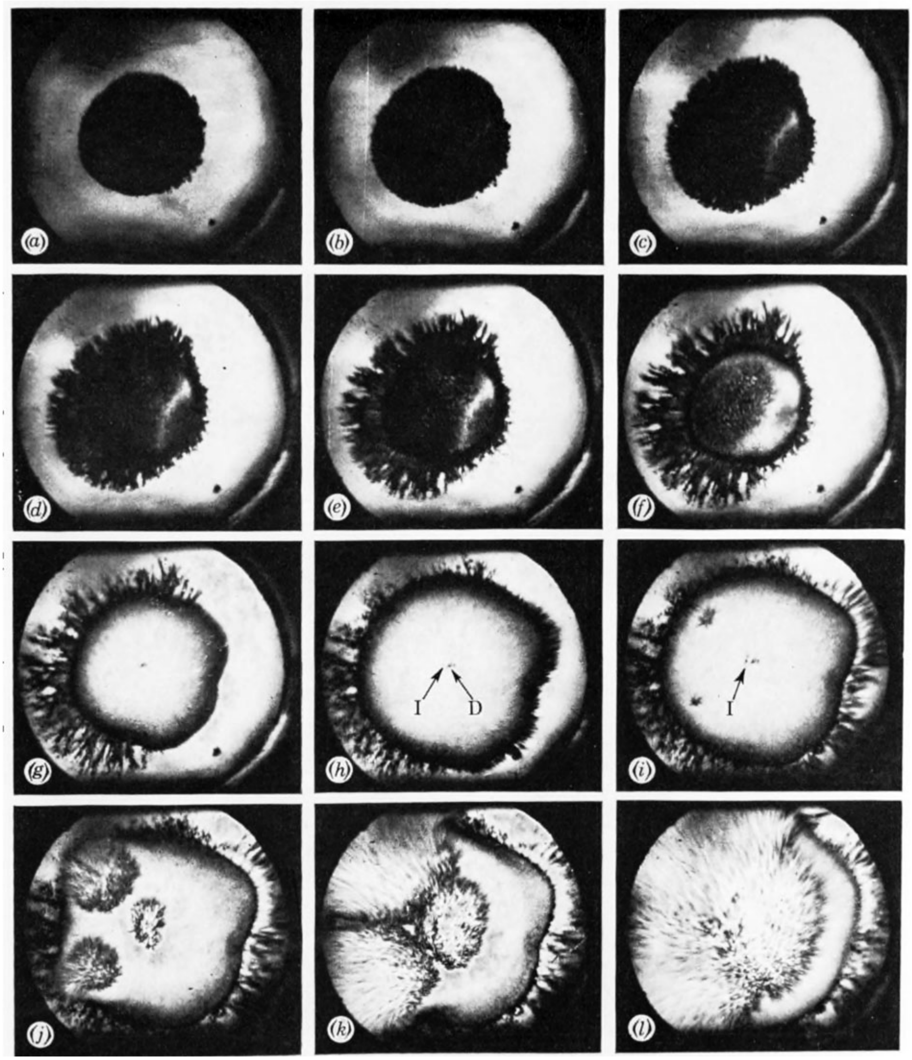



Figure 6. Selected frames from the high-speed photographic sequence of impact of 14 mg of PETN powder between glass anvils. Interframe time 5.5 μs. Diameter of the field of view 20 mm. From (10), with permission from the Royal Society.

were a major part of John's research interests up until his retirement (50). He and members of his research group experimentally discovered additional hot-spot mechanisms for solid secondary explosives, namely adiabatic shear bands (11), fracture (20), polymer fracture (16) and pressure–shear (39). This understanding is critical for effective prediction of the hazards inherent in energetic materials. The results obtained provided a bedrock for that prediction and so helped save lives and prevent accidents.

A rotating mirror camera that played a major role in the study of energetic materials in John's group was the C4. This had been designed at the British Atomic Weapons

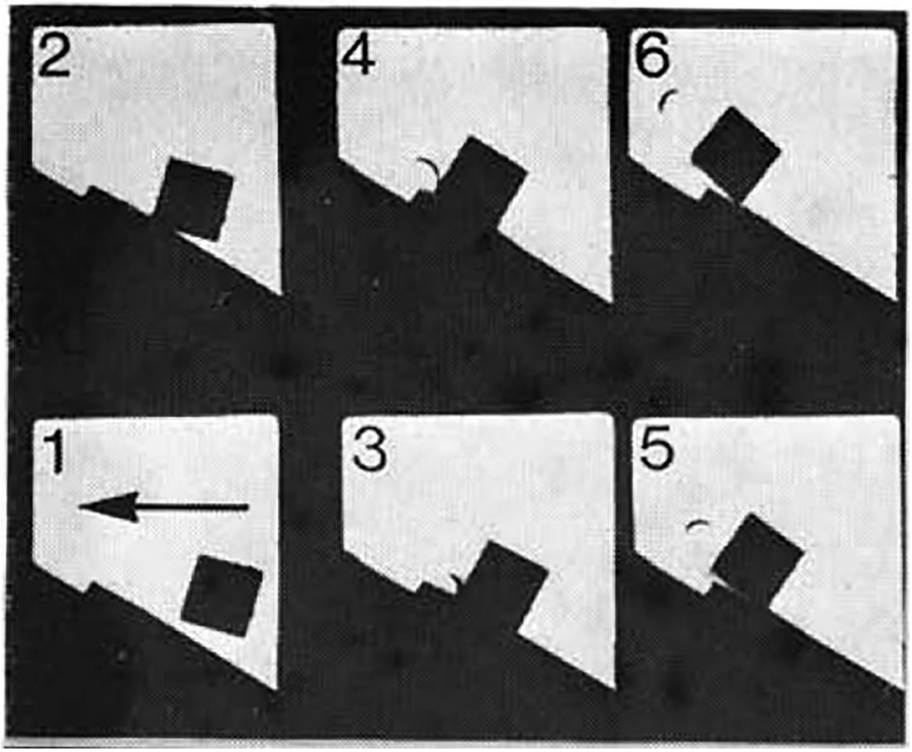



Figure 7. High-speed photographic sequence of the impact and subsequent back-rotation of an 8 mm square, 1 mm thick tool-steel plate on mild steel. Impact parameters: 186 m $s^{-1}$, 30°, rake angle −15°. Interframe time 19 μs. From Hutchings (1977).

Establishment (AWE) in the mid 1950s for obtaining high-speed photographic sequences of atmospheric nuclear explosions (Coleman 1959). The C4 could take 140 photographic images with a 5 μs interframe time. It was not until around 2005 that electronic cameras were marketed that could take a similar number of pictures with microsecond precision, albeit with inferior picture sharpness. Since electronic cameras are much easier to use and much smaller than rotating mirror cameras, the group gave their C4 to the Science Museum in London in 2012, who returned it to its original appearance and put it on show for 15 months starting in January 2015 as part of an exhibition entitled ‘Churchill’s Scientists’.

### *Erosion*

Studies of the erosive wear of metals by solid particles followed the well-tried approach handed down to John from Bowden (12) (Hutchings 1977) (figure 7): first try to understand a simple system, in this case single particle impact, before attempting to understand something more complicated, such as multiple impacts. Inspired by a visit to RARDE Fort Halstead, Hutchings designed gas-guns with a double-diaphragm firing mechanism to perform these studies (Hutchings & Winter 1975; Hutchings *et al.* 1977). Laboratory gas-guns were subsequently used in many other projects (15, 22, 36, 44), a number of them classified.

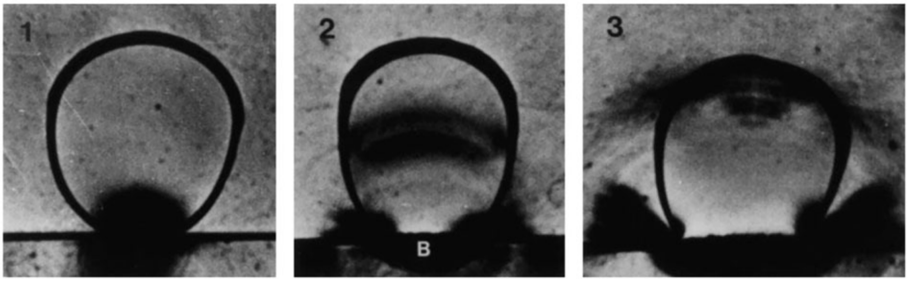



Figure 8. Generation and propagation of shock waves within two-dimensional 2 mm diameter water drops captured at different times after impact at 70 m $s^{-1}$. From (49).

In 1978, John funded a post-doc position for David Andrews to develop a solid particle erosion rig along with associated novel instrumentation (Andrews 1983a,b). His erosion rig is still in use, modified to be compatible with changes in pressure vessel regulations. An overview of solid particle erosion studies performed in John's group was published in 2005 (45).

Between 1979 and 1987, John organized a series of international conferences on erosion by liquid and solid impact. These grew out of the rain erosion conferences that began in West Germany in 1965 before moving to Farnborough in 1967 (Fyall & King 1967). Their success owed a great deal to John's ability to obtain funding and to attract leading international researchers as speakers.

John's long-standing interest in both liquid impact and the initiation of explosives by the collapse of bubbles (9) led to the development of a two-dimensional gelatin technique. This geometry was originally used by his student Jean-Jacques Camus to allow clear visualization of the generation and interaction of shock waves within drops of water (figure 8).

When John Dear revived this technique in the 1980s (23), he generated shock waves in gelatin using rectangular metal projectiles fired from a rectangular-bore gas-gun (Hutchings *et al.* 1977). This technique was also applied to the study of jet formation in cavities in gelatin that were in the process of collapse by a shock wave (24). This work was continued and developed by Neil Bourne (30). The pioneering research led by John on visualizing shock waves, bubble collapse and hot-spot generation was very valuable to the cavitation and explosives research community, and many modellers used these data to validate the complex models that they developed.

In 1984 John's interests branched out to the study of bubble acoustics as a result of an undergraduate project performed by Timothy Leighton (FRS 2014) on the sound produced by gas bubbles when injected into liquids (Leighton & Walton 1987). John jointly supervised this project with Alan Walton, who had just arrived as a sabbatical visitor to the Cavendish from the Open University. A subsequent student, Hugh Pumphrey, used the technique to study the sound of rain falling onto oceans (Pumphrey & Walton 1988). This rainfall study was undoubtedly the spark that lit numerous studies in the USA, which eventually led to the development of commercial acoustic rainfall sensors that have been fitted to ocean-going buoys to gather weather data. Leighton moved to the University of Southampton in 1992 and established a group studying the physics of the interactions of sound with bubbles, and their applications in engineering, medicine, chemistry, the behaviour of marine mammals and fishes, microbiology, oceanography, extraterrestrial environments and climate change.

### *Rock blasting*

One early result of John's collaboration with research engineers at Luleå in Northern Sweden (see below) was his interest in the effects of explosions in connection with rock blasting (7). This interest remained with him up to and beyond his retirement (51). Owing to his links with De Beers, John became involved in the early 2000s with a multinational collaboration, the Hybrid Stress Blasting Model, formed to investigate improving the efficiency of mining operations. Two PhD studentships in the Cavendish were taken up by Geoff Willmott (Willmott 2004) and Chris Braithwaite (Braithwaite 2009) to study the shock properties of rocks. As commodity prices were high at that time, the mining companies involved had significant resources to assign to the project. This meant that it was possible to make rapid progress in what is a complex field of study.

Highlights of the gas-gun work include evidence of failure waves in glasses, high-speed fracture of diamond by Willmott, the first measurements of unloading behaviour in shocked sand by Braithwaite—helping to demonstrate the robustness of scientific instruments for Space applications—and examining the effect of stone chips on the wheels of the Bloodhound supersonic car.

Over the course of the project, the results, for example examining the difference between the static and dynamic tensile strength of rock materials, were included in a rapidly developed computational code. This could then be used on a laptop by a mining engineer to design the blasting patterns in the mine based on a physically realistic simulation of the situation on the ground.

### *Optical techniques*

John was always keen to learn from other researchers, and invited many to spend their sabbaticals at the Cavendish to pass on their skills to his team. An important example was Fu-Pen Chiang of the State University of New York, who introduced John's group to the use of moiré and speckle interferometry. This led to the application of speckle interferometry to measure displacement fields in dynamic fracture (18). Further developments of this technique were made by John's research assistant Stewart Palmer and research students Jon Huntley and Tim Goldrein. In the 1980s, they were the first to apply speckle to mapping strain fields in polymer-bonded explosives (PBXs) undergoing deformation (19). This provided strain-to-failure data for new PBX formulations, which was important for assessing their suitability for eventual deployment. The stress–strain data, and parallel optical microscopy studies, also allowed failure models to be explored, demonstrating, for example, the presence of deformation twinning of HMX crystals and its likely role in the failure of HMX-based PBXs.

### *Shock physics*

In the early 1990s, there was a growing requirement in the UK for an experimental shock physics capability. This led Neil Bourne and co-workers to construct a single stage gas-gun capable of firing projectiles at velocities up to 1.1 km $s^{-1}$ (36). The target chamber was instrumented to provide time-resolved data on shock wave propagation and material response, in order to validate material models and numerical simulations. Failure waves in silicate glasses were first proposed by Russian shock physicists in the early 1990s

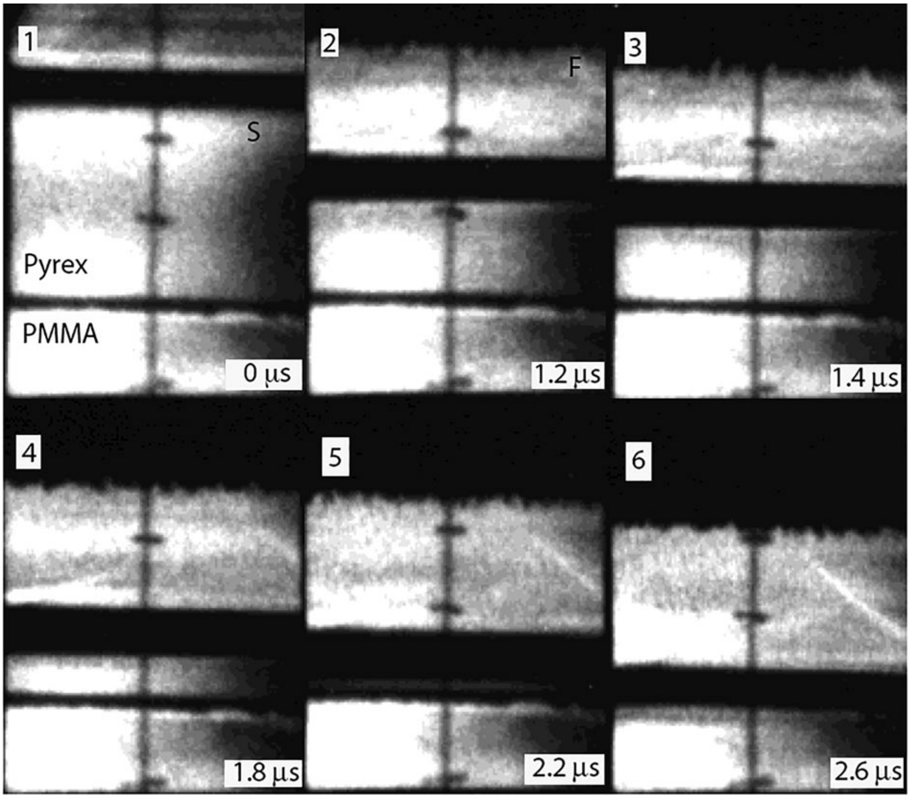
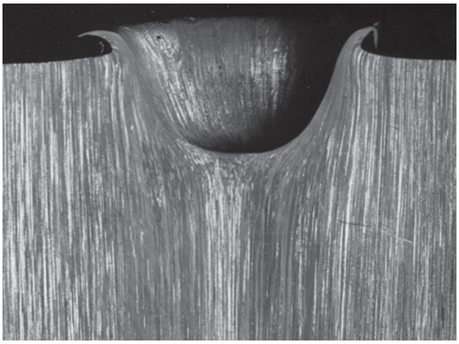



Figure 9. Borosilicate (Pyrex) glass impacted from the top at 250 m $s^{-1}$. A shock S and a failure front F can be seen travelling down through the frames. The scale markers are 5 mm apart and the first is 15 mm from the impact face. From (35), with permission from American Institute of Physics.

(Rasorenov *et al.* 1991) to explain a small increase in compressive shock stress that they detected on the rear surface after the main shock pulse had begun to decay. They attributed this ‘reload’ signal to partial reflection of the tensile shock pulse, formed by reflection of the compressive shock from the rear surface of the glass specimen, from a front of failed, and hence mechanically weaker, material propagating some distance behind the shock wave. This explanation was brilliantly confirmed by the sequence of images shown in figure 9. Shocking of secondary explosive powders using the laser-flier technique funded by AWE also began to be studied in John’s group about this time (40, 41).

When Neil Bourne and others started building the plate impact facility in the Cavendish, it had been some time since shock experiments had been performed in the group on solid materials. The previous PCS study had been undertaken by Wilson in the 1960s in connection with the risk to spacecraft by hypervelocity impact (figure 10) (Wilson 1967). John had co-authored a conference paper with Wilson on this topic in 1965 while he was still a research fellow (3).

(*a*)



(*b*)

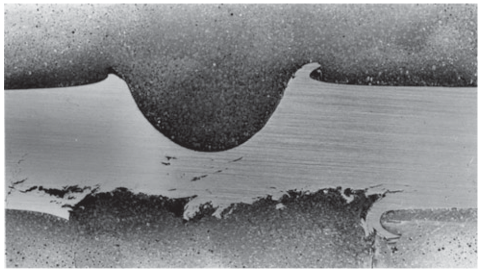


Figure 10. Optical photographs of (*a*) the etched cross-section of the crater produced in an aluminium block by the normal impact of a 0.25 g, 6 mm diameter, 6 mm long polyethylene cylinder at about 7 km s$^{-1}$. (*b*) The spall produced by the reflection of a three-dimensional shock wave at the back surface of a 1 cm thick copper plate subjected to hypervelocity impact. From Wilson (1967).

## International collaborations

John's international collaborations began in the early 1970s with the Atlas Copco Research Laboratory in Lausanne, Switzerland. There he met Bengt Lundberg and Martin Lesser, with whom John co-authored some important papers on liquid impact on solids (13, 17). A few years later, when Martin and Bengt became respectively the first professors in fluid mechanics and solid mechanics at the newly-founded Luleå University of Technology in Northern Sweden, a research exchange programme was initiated and John spent at least two weeks in Luleå every spring for the rest of his career, preferably in March when the visit could be combined with cross-country skiing. John strongly influenced the research performed at Luleå, the university's laboratory for experimental mechanics being named the John Field Laboratory in his honour (figure 11). In 1989 he was awarded an honorary doctorate by Luleå University.

During the 1980s and 1990s, John's summer visits to the Laboratoire de Machines Hydrauliques at the École Polytechnique Fédérale de Lausanne (EPFL) in Switzerland focused on the study of bubble collapse using the cavitation tunnel there (42). These visits also provided an opportunity for John to indulge his love of mountain walking.

He developed strong links with the National University of Singapore as well, spending a semester there as a visiting professor at the Impact Mechanics Laboratory in 1999. During his visit, he delivered a course of lectures entitled 'Shock waves and explosives', which arose out of the development by Neil Bourne of the plate impact facility in John's laboratory (36). This led to a number of subsequent short-term visits, during which several lab members would have a meal with him and Ineke at a particular favourite local restaurant.

## The UK Ministry of Defence

Following the example of Bowden, John showed a willingness over many years to tackle difficult scientific problems of interest to the UK MOD that could be used to solve engineering


Figure 11. Photograph of John Field taken in 2014 at the entrance of the laboratory in Luleå named in his honour. (Online version in colour.)

problems. A priority topic for the MOD concerned the radomes used to protect sensors on missiles and aircraft. Damage was caused in flight by the high velocity impact of fine solid or liquid particles in the atmosphere. John and his team developed facilities that used compressed air either to fire water drops (25) or small solid particles (45) at high velocity against candidate infrared-transparent materials. Both facilities could be operated over long time periods, allowing the cumulative damage to be assessed (37, 38), and hence provide the physics understanding necessary to design damage-resistant radomes.

John's research expertise in explosives led to his active support of several research areas within the MOD, both as an advisor and as an experimenter. In his advisory role, he was a member of several committees, including the Defence Scientific Advisory Council and the Nuclear Research Advisory Committee, which advised the MOD's Chief Scientific Advisor on the research programme in both conventional and nuclear weapons. He was also an active member of the committees that oversaw the research activities carried out by the UK's defence research establishments in energetics and terminal effects. Consequently John had very high level security clearance, requiring him to report any contacts he had with Russian scientists at international conferences. This did not impact his love of Russian literature—Ineke recalls his affection for the novels of Dostoevsky, Sholokhov, Turgenev, Tolstoy, Chekov and Solzhenitsyn.

From early 1985 John chaired the Energetic Materials Research Committee (EMRC), which in 1997 became the Terminal Effects and Energetic Materials Advisory Committee. EMRC meetings were always challenging, but enjoyable, as John, Peter Gray and John Clarke between them covered all the major elements of the UK energetics research programme and were skilled at asking probing questions of the research teams. John demonstrated a flair for predicting whether or not a line of research was likely to be successful and the benefits that would accrue. He was always keen to encourage new research, developing an annual conference at which results could be presented and discussed with senior academics in the context of an enjoyable social networking event.

John was much liked and respected by the MOD energetics research community, as he strongly supported them when explosives research was under serious threat in the UK. He was influential in persuading government ministers that the cause was worth fighting for, and for many years secured a sound research and development base. This helped keep the UK at the forefront of world research in this area.

## Personality and evaluation

John was a complete all-round academic, carrying out research at the highest level, inspiring his colleagues and students and contributing strongly to the Cavendish's teaching programme (see Andrews *et al.* (2021)). As a lecturer during the 1980s, he preferred traditional 'chalk and talk' to the overhead projectors used by most lecturers of that era, with distinctive left-leaning handwriting that was difficult to follow at times. His lectures provided invaluable physical insights into more abstract concepts and brought the subject to life. He also had a great sense of humour, often dry and with such a deadpan delivery that one was not always sure if he was joking or not.

Like his distinguished predecessors, his concerns were mechanisms of direct practical consequence on the macroscopic and mesoscopic scale: one thinks of Thomas Young, perhaps the founding father, then G. I. Taylor, A. A. Griffith FRS and Philip Bowden, concerned with fracture and response to impact as it relates to everyday life and to military armament. Like all of these, John's forte was to choose experiments simple enough to produce far-reaching results, then to design and to find resources sufficient to carry them out effectively, and finally to write elegant papers of lasting interest in journals of the highest quality.

John was always very keen on physical exercise, be it running, cycling or skiing. During the Easter vacation, when he was in northern Sweden, he adopted his usual 'work hard, play hard' approach. After an 8 a.m. start, he would typically be doing gas-gun impact experiments through the day with Allan Holmgren. At about 4 p.m. he would wander over, suggesting it was 'time for a bit of exercise'. This would consist of a circuit round the 5 km or 10 km ski trail just off the campus. Huntley has written:

> Before Sweden, if I had had to summarise John's character in a few words, I would have said: hard-working, intelligent, competitive, conservative. The Swedish trips revealed to me other sides to his personality: kind, humorous, cultivated, sociable and generous. (Andrews *et al.* (2021))

Although John was often stressed owing to the intensity with which he worked, it was rare that members of his group saw him angry. John was regarded by Huntley as an ideal PhD supervisor:

> He sketched the outlines of the big picture, and provided all the paints I requested, but left the detailed brushstrokes to me. He was no backseat driver. The group he led was focused on the applications of physics, which meant regular meetings with, and presentations to, our industrial and defence establishment sponsors. These contacts helped keep one's feet on the ground, and the income from them meant that new lines of research could be supported at short notice. The working environment was enriched by the very diverse range of projects his students and post docs were engaged in, together with sabbatical visits by senior scientists from around the world. (Andrews *et al.* 2021)

John's love of books and learning extended to the PCS as well. Philip Bowden started the PCS library in the 1940s as the research interests of the group were rather different from those of the rest of physical chemistry and the Cavendish. John built it up and was always generous in generally agreeing to suggestions for new purchases—it now contains over 1700 items, as well as the 340 group PhD and Master's theses.

Bill Proud recalls that John regarded his research group as a family, promoting the interests of its members and ensuring they were treated fairly and reaped the rewards of their efforts. John was particularly supportive of, and took an interest in, the clerical-administrative staff and particularly the technical staff. Their mutual high regard ensured their full inclusion in the life of the group. He maintained contact with group members and gave Bill the following advice: 'Always ensure that your students are better informed, better educated and given the opportunity to reach further than you have, because what is the alternative?' After retiring in 2003, John was always willing to come to meetings, if asked, keen to ensure relationships were maintained, but also giving space to those who carried the group forward to grow into new roles.

John very effectively managed the expectations and needs of the funding organizations that paid for the research performed in his group. These funding bodies included US and UK military establishments as well as private companies. John was undoubtedly a worthy successor to both Philip Bowden and David Tabor, especially with regard to the importance of 'simple' direct experimental design and the capability to research and solve real world problems as well as perform high quality fundamental materials research.

In summary, John Field created a world-class research group with associated pioneering facilities for the study of the dynamic properties of materials that attracted researchers from around the world and provided experimental data that enabled new ideas in materials science to be developed and their models to be validated. He enabled the UK research effort in the response of materials to dynamic loading to maintain its world leading position.

## Honours and awards

1987 Order of the British Empire (OBE)
1989 Honorary doctorate, Luleå University, Sweden
1990 Duddell Medal, Institute of Physics

2002 Honorary Fellow of the Royal Society of South Africa
2009 John Rinehart Award, DYMAT Association

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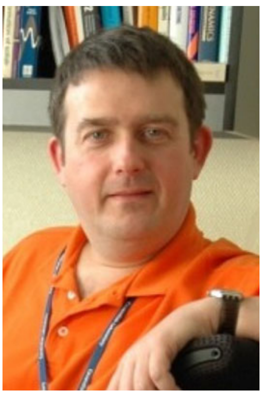
The portrait photograph was taken in 1994 by Prudence Cuming Associates and is © the Royal Society. All other photographs were kindly provided by the Field family.

## Author profiles

### *Stephen Walley*

Stephen Walley graduated PhD from the University of Cambridge in 1983, following which he worked as a research associate in the PCS Group of the Cavendish Laboratory. Retiring in 2014, he remains professionally active in the Fracture and Shock Physics Group. He has co-authored about 120 papers on the solid particle erosion of polymers, ballistic impact on glass/polymer laminates, the ignition mechanisms of propellants and explosives, and the high strain rate mechanical properties of polymers, metals and energetic materials. In retirement he continues to write papers and book chapters of a more historical nature, as well as writing-up for publication studies performed in recent years by members of the Fracture and Shock Physics Group.

### *William (Bill) Proud*



Bill Proud obtained his PhD in chemistry at the University of Newcastle upon Tyne before spending two years as a post-doctoral researcher at the University of Barcelona. He joined the Cavendish Fracture group under John Field in 1994 and initially worked on electro-thermal propulsion research. His interest in the relationship between the initiation of energetic reactions and the energy released was supported by the Engineering and Physical Sciences Research Council (EPSRC) for three years. In 2003, he became head of the Fracture and Shock Physics Group upon the retirement of John Field, and in 2009 was appointed reader at the Institute of Shock Physics at Imperial College London. There, he was involved in establishing the Royal British Legion Centre for Blast Injury Studies. In conjunction with the Institute of Security Science and Technology, he developed a masters degree course mixing elements of physical science, computing, engineering and behavioural science.

*Timothy Leighton*

Timothy Leighton FRS is the professor of ultrasonics and underwater acoustics at the University of Southampton, the founder and chair of the Global Network for AntiMicrobial Resistance and Infection Prevention (Global-NAMRIP), and director and inventor-in-chief of Sloan Water Technology Ltd. His PhD, awarded in 1988, was supervised by John Field and Alan Walton. Following the award of an EPSRC advanced research fellowship, he took up a lectureship at the University of Southampton in 1992, followed by a readership in 1997 and a personal chair in 1999. The group he founded there focuses mainly on various aspects of bubble acoustics, but he also publishes on animal behaviour, climate change, chemistry, healthcare and microbiology. His inventions across many disciplines resulted in his election as FREng in 2012, FRS in 2014 and fellowship of the Academy of Medical Sciences in 2018. His eight international medals include the Clifford Paterson Medal and the Brian Mercer Award for Innovation of the Royal Society.

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