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REVIEW ARTICLE

Contributions to Dynamic Behaviour of Materials Professor John Edwin Field, FRS 1936–2020

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Abstract
Professor John Edwin Field passed away on October 21st, 2020 at the age of 84. Professor Field was widely regarded as a leader in high-strain rate physics and explosives. During his career in the Physics and Chemistry of Solids (PCS) Group of the Cavendish Laboratory at Cambridge University, John made major contributions into our understanding of friction and erosion, brittle fracture, explosives, impact and high strain-rate effects in solids, impact in liquids, and shock physics. The contributions made by the PCS group are recognized globally and the impact of John's work is a lasting addition to our knowledge of the dynamic effects in materials. John graduated 84 Ph.D. students and collaborated broadly in the field. Many who knew him attribute their success to the excellent grounding in research and teaching they received from John Field.

Keywords Explosive · Liquid · Shock · Impact · Friction · Fracture

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Biography of Prof. John E. Field, FRS (1936–2020)

John Edwin Field was born on 20 September 1936 in Stourbridge, Worcester.

His family were not scientists, but his lifelong interest in physics was sparked by two older neighbourhood children who went on to study it at University. As a result, John graduated from University College, London in 1958 with a First Class degree in Physics. He then moved to Cambridge to perform research for a Ph.D. under the supervision of Frank Philip Bowden FRS. Bowden was the founder of the Physics and Chemistry of Solids Group in the Cavendish Laboratory (the Department of Physics of Cambridge University) where John would spend the rest of his career. John was awarded his Ph.D. in 1962 for his thesis entitled "*High speed liquid impact and the deformation and fracture of brittle solids*" [1].

It was in Cambridge that he met his wife, Ineke, who was working in the University Library. They married in Cambridge in 1963. They have two sons, one daughter, and five grandchildren.

In 1964, John was elected to a Research Fellowship at Magdalene College Cambridge. Two years later, he was elected an Official Fellow of the College, a position he held from 1966 to 2003 during which time he was successively a University Demonstrator, Lecturer, Reader and Professor (from 1994). Despite being immensely busy with his research and major administrative roles in the Cavendish Laboratory, John found time to help countless graduate students and undergraduates in his college as well as maintaining his enthusiasm for cross-country running.

Following the untimely death in 1968 of Philip Bowden, David Tabor became head of PCS and John took over the supervision of two of Bowden's Ph.D. students, Graham Coley and Munawar Chaudhri, who were studying liquid explosives and solid primaries respectively. John's interest in these materials soon extended into secondary explosives through his supervision of Stephen Heavens. Such studies remained a major part of John's research interests up until his retirement in 2003.

Over the years John expanded his group within PCS and was an enthusiastic proponent of photographing high-speed events as a method of explaining the complex phenomena. Before it became fashionable at universities, he was also skilled at obtaining research funds and grants from industry and Government to support both students and expensive equipment purchases.

Because of a collaboration on some papers in the early 1970s about liquid impacts on solids with two of the founding Professors at Luleå University of Technology in Sweden, John spent at least two weeks in Luleå every spring for the rest of his career (Fig. 1), preferably when the cross-country skiing was good.

Another university with which he developed strong links was the National University of Singapore (NUS). He first went there in 1999, spending a semester as a Visiting Professor at the Impact Mechanics Laboratory, during which time he delivered a course of lectures entitled "*Shock Waves and Explosives*". These lectures arose out of the development by Neil Bourne in the early 1990s of a shock physics capability at the Cavendish.

As part of his wide-ranging scientific interests, John was also heavily involved with research into the fundamental properties of diamond. For many years he was Secretary of the annual diamond conference. For the benefit of people new to the field, John also edited two books on the properties of diamond.

John Field leaves behind a legacy of scientific innovation, intellectual leadership and two generations of students and scientists who benefitted from his mentorship.

Reminiscences

Over his career, Prof. John Field graduated 84 Ph.D. students (see "Appendix"), mentored numerous students and postdocs. He impacted numerous researchers around the world. This was through both his direct friendship and collaboration and indirectly through his extensive publications and by his students going off into the world and expanding his legacy. He was a physicist by training, and pursued an array of fundamental and applied research areas. John's major contributions can largely be aligned into friction and erosion, brittle

Fig. 1 A photograph of John Field taken in 2014 at the entrance of the laboratory in Luleå, Sweden, named in his honour

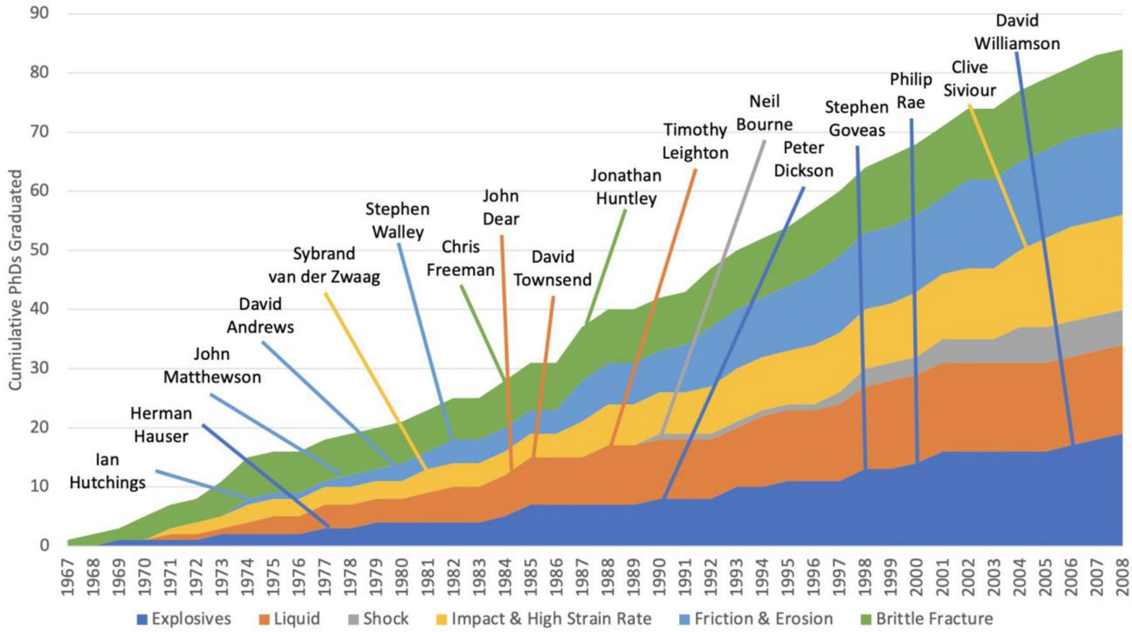

Fig. 2 Professor Field's cumulative Ph.D. students graduated by focus area

fracture, explosives, impact and high strain-rate effects in solids, impact in liquids, and shock physics. As shown in Fig. 2, John pursued these areas relatively equally over time, with shock physics being an area of study coming in the late 1980s. Many students worked across these areas over the course of their studies. They worked together sharing equipment with the more senior students often playing important mentoring roles with the newer members of the group. This paper offers reminiscences from several of John's students and collaborators, offering both personal anecdotes from their relationship with John, which often lasted long beyond their time at Cambridge, and highlighting technical contributions they made with John. Figure 2 seeks to illustrate the primary areas of John's research that the contributors to this paper focused on for the doctoral work and the year they completed their Ph.D. The following sections offer reminiscences from students in the chronological order in which they completed their Ph.D., interspersed with contributions from other visitors in the time they visited the Cavendish.

Ian M. Hutchings, Emeritus GKN Professor of Manufacturing Engineering, University of Cambridge, Ph.D. Awarded 1975—The Erosion of Ductile Metals [2]

Ian M. Hutchings first met John Field in 1971 shortly after Ian's final examination results came out. After a brief chat in the Physics and Chemistry of Solids (PCS) Group tearoom (in a very ramshackle corner of the Old Cavendish site) John offered Ian a place as a Ph.D. student. A research topic of erosion by solid particle impact was mentioned, but it was a subject of which at that point Ian knew nothing, and he suspects John knew only marginally more. Until then, Ian had been planning to join Imperial College to study nuclear reactor physics, but his meeting with John changed his direction of travel completely.

Within days of starting research, under the enthusiastic and wise guidance of Ron Winter (Ph.D. 1971 [3]), Ian was accelerating small particles by spalling them off a thin copper shim placed above an electrical detonator. The detonator was fired by using a screwdriver blade to short two bare wires connected in series with the detonator and the mains, a process that even now fills Ian with horror. Ian recalls being initially much happier when Ron—who seemed unafraid of any hazards despite his apparent wisdom—set the thing off, rather than having to do it himself.

With experience, Ian became more accustomed to the apparently relaxed approach to safety that characterised the group's practical research in those days. Ron's lab—and office—had a window in recognition of his seniority, while Ian was given a desk in a gloomy and very cluttered underground room that he shared with Keith Fuller (Ph.D. 1973 [4]), then writing up his thesis and working nocturnally. Ian recalls he does not think he met Keith at all for the first couple of weeks. A current research student in the Cavendish has commented in a recent issue of the alumni magazine (CavMag [5]) on the lack of hierarchy and the willingness of researchers at all stages of their careers to collaborate. Exactly the same applied within John's group 50 years ago.

The space then occupied by PCS, in buildings on Free School Lane in the centre of Cambridge, was a rabbit-warren of rooms full of old experimental lash-ups as well as rigs in current use. There was apparatus on desks and papers on laboratory benches, but it was nevertheless packed with friendly people. Specialist kit, such as the high-speed cameras, was housed separately, and Ian quickly learned that the rising scream of the mirror turbine of the Beckmann and Whitley 189 at any time of day—or night—would soon be followed by a loud bang from yet another impact or explosive event. The cheering that ensued when the lighting and camera were found to have captured the event with perfect synchronisation came later, after the film had been developed in the darkroom.

Research in PCS into the impact of high-speed liquid jets, with practical application to raindrop impact on aircraft and missiles as well as erosion of steam turbine blades, had been started by Philip Bowden in the late 1950s, with John Brunton as his research student [6], and had included high-speed photography using the Cranz-Schardin technique. John Field extended this work [7], and also studied the effects of stress waves on fracture [8], with the great benefit of the Beckman and Whitley rotating mirror camera acquired by Bowden from DuPont [9].

Ian's own studies of the erosive wear of metals by solid particles [10, 11] (Fig. 3) followed the well-tried approach handed down to John Field from Philip Bowden: first try to understand the effects of a single impact before attempting the more complex question of multiple impacts. Spalling particles from metal shims was insufficiently reproducible, and an air rifle clamped to the bench (as used to generate high speed liquid jets by Brunton and many subsequent researchers including John himself [7]), insufficiently flexible. Following a visit to the Royal Armament Research and Development Establishment (RARDE) Fort Halstead facilitated by John's contacts in the world of defence research,

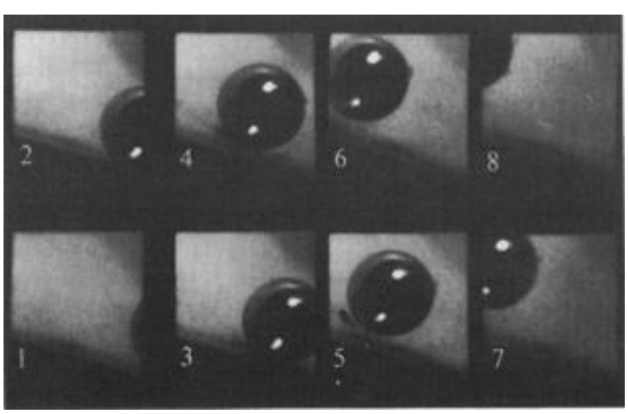

Fig. 3 High-speed photographic sequence of the impact of a 9.5 mm diameter steel sphere on mild steel. Impact parameters: 210 m s^{-1}, 20°. Interframe time 19 µs. Camera used Imacon 790. From [13]

Ian designed a gas gun with a 16 mm bore and a double-diaphragm valve, which proved a very versatile piece of apparatus that was subsequently used in many later projects [12]. Having built the gun himself in the PCS workshop, Ian naively pressure-tested the reservoir, breech and barrel with nitrogen gas at 100 bar, completely oblivious to the damage to life and limb that would have followed had they failed.

The development of ingenious experimental techniques and their exploitation played a major role in John's research group. Most students were expected to build their own apparatus, and the training in research methods was 'hands-on'. John's success in attracting research money from government and industry meant that there was no lack of funding for research students, postdocs and support staff, as well as state-of-the-art high-speed photographic equipment which was widely used throughout the group. Ian was fortunate to have access to a newly acquired Hadland Imacon 790 image-converter camera for some of his own work (Fig. 3) [10]. Studies of erosive wear by subsequent members of John's group were reviewed by Walley and Field shortly after John's retirement [14].

John was an enthusiastic lecturer at meetings and conferences, and the high-quality photographs with which he illustrated his talks were always impressive, a tribute not only to the skills and equipment of his research team, but also to the talents of the group's photographic technician, Alan Peck. John was also an energetic organiser of meetings, including the series of International Conferences on Erosion by Liquid and Solid Impact (ELSI) held in Cambridge, for which he served as Conference Secretary and Editor of the Proceedings from 1979 to 1987. Their success owed a great deal to John's personal efforts to find additional funding and to attract the leading international researchers to Cambridge. The ELSI conferences continued under that name until 1994 [15], and John presented an invited paper on liquid impact at the following meeting in 1998 [16].

In the spring of 1973 John's research group was one of the very first to move to the New Cavendish Laboratory on the University's West Cambridge site. In his history of the Cavendish Laboratory, J.G. Crowther wrote that "*instead of grimy congested little workplaces and cellars there were light, shining rooms, surrounded by vistas of green fields, trees, and even a lake*" [17]. All true, but the old labs and the research carried out there within John Field's group had a special character which Ian remembers with nostalgic affection.

Michael Swain, Professor Emeritus of Biomaterials, University of Sydney, PCS Postdoc 1975

Michael Swain first met John Field after he joined PCS at the New Cavendish in April 1975. Michael had been offered a post-doc position to join the group by David Tabor [18] when he had briefly visited Cambridge the previous year. The research area of Michael's activity was on the mechanical properties of novel glasses that formed the basis of the protection for various missile detector and guidance systems and was supported by a grant that John had. During this period, Michael worked very closely with Joe Hagan (Ph.D. 1973 [19]) on a range of problems from slow crack growth studies to indentation deformation and fracture [20–22]. Towards the end of Michael's stay, Joe and he began extending some of John's early work on water jet impact initiated stress waves on crack initiation and growth in glass. In addition, Michael had the opportunity to work with Munawar Chaudhri on high speed photography of cracks initiated in glass by the impact of small metallic spheres [23].

Michael's arrival at PCS occurred not long after the lab had been transferred to the new site, which was somewhat remote from the rest of the University. Also, the lab was still in the process of unpacking and a tremendous amount of "*stuff*" was to be found in the cupboards of the lab. For an experimentalist there were tremendous opportunities to conduct research on a range of topics not only the ones that formed the basis of the grant. The excellent home-made gas gun systems for generating high speed particulate and water jet impact, plus the high-speed photography systems, provided the opportunity to engage in impact deformation and cracking research of various materials. Not long after Michael's arrival at PCS, John went on an extended (18 month) sabbatical to Sweden and Switzerland which left Joe and Michael free to explore a wide range of topics, some of which caused John's wroth upon his return. A particular case was the work Joe and Michael did investigating the role of Rayleigh waves induced by water jet impact to initiate and extend cracks from previous indentation flaws [24].

One of Michael's major disappointments during his stay at PCS was that he never really got to know John. They did have the occasional group meeting but there were no opportunities to get to know him socially. Even though most academics, technicians and students at the Cavendish participated in the daily morning and afternoon tea ritual it was rare that John joined the group during Michael's stay. To his credit John was very supportive of his students and post-docs enabling them to attend major international conferences and visits to various labs abroad. In conclusion, Michael shared that he is exceptionally grateful for the opportunity John provided him to undertake a post-doc at PCS.

Hermann Hauser, Information Technology Entrepreneur, Ph.D. Awarded 1977—Mechanically Activated Chemical Reactions [25]

Hermann Hauser was introduced to John Field by Jacob Israelachvili in Tabor's group, who was working on his van der Waals force measuring instrument at the time. Jacob was kind enough to propose Hermann as a research assistant to John's group whilst he was doing his physics studies in Vienna where Hermann had met Jacob as a language student the previous summers.

His reception as a research assistant in John's group could not have been more friendly. Hermann was immediately accepted as an, all be it very junior, member of the group. His first job was to calibrate an airgun for John Camus. Hermann's workplace was in the windowless cellar lab in the old Cavendish Laboratory in Free School Lane. The group spirit that John managed to create was wonderful. Hermann was particularly impressed by teatime which was observed religiously and the whole group including John were always there and always willing to give advice and answer questions. It was a happy time with a lot of work but also many pranks. One of Hermann's favourites was to use a syringe to squirt water from the room next door through a small window onto hard working Ph.D. students like Keith Fuller (Ph.D. 1973 [4]), Ian Hutchings (Ph.D. 1974 [2]), and David Gorham (Ph.D. 1974 [26]) who would than seek revenge with similarly harmless antics a few days later.

John himself had worked out some impressive routines to avoid being disturbed by unwanted visitors. He would come down to see students in the lab pretending to start a high-speed camera experiment to record explosive events by sounding a very loud bell. This was to let people, especially visitors, know that it was very dangerous to get anywhere near the lab during the experiment which, of course, could last for hours as the secretary was instructed to explain.

When Hermann had finished his studies in Vienna, John was kind enough to offer him a place to do a Ph.D. in the PCS group which Hermann was absolutely delighted to accept. Hermann's doctoral research resulted in the following publications on explosives [27–30].

Shortly after Hermann's start as a Ph.D. student the group moved to the New Cavendish on Madingley Road. They could not believe how modern and spacious the new labs were compared with the rather dingy rooms at the Old Cavendish but nevertheless the group spirit remained the same. It was mainly due to John's ability to be so supportive of his Ph.D. students and his ability to raise money from many different sources. One such grant was from de Beers, the large diamond company.

This led to an annual diamond conference where the group were to show all the work they had done during the year. This led to an annual routine: John would come down to see the students and tell them that results were needed for the conference. Since none of students had done any diamond work during the year the whole group scrambled to produce useful papers in record time as there were normally only two or three weeks left until the conference. This very concentrated and focused effort actually produced some good results albeit with a bit of stress and sometimes burning of the midnight oil [31].

As part of Hermann's Ph.D. thesis, he developed a new analysis method for thermogravimetric and differential scanning calorimetric data [28], which were data logged and processed by spline software written in the Computer laboratory (probably still called the Mathematical Laboratory). The lab was located in the adjacent Austin building which could be reached via a lofty bridge on the 4th floor. It was this work on the IBM360 using FORTRAN, which started Hermann's interest in Computing, and he joined the University Microprocessor Group. This led to the ARM processor.

Hermann shares that he will always remember John as a generous and supportive 'Doktorvater'.

M. John Matthewson, Professor of Materials Science and Engineering, Rutgers University, New Jersey, Ph.D. awarded 1978—Protective Coatings and Mechanical Properties of Materials [32]

John Matthewson went up to Cambridge to read Physics with a plan to join one of the Astronomy groups for graduate work. However, in his final (third) year, he met John Field who was his supervisor for a Materials Science optional course in Part II Physics. For each meeting, John Field would give some help with the course and then show slides of his research results. This awoke John Matthewson's interest in Materials Science and eventually he asked to join John Field's group for a Ph.D. John Field asked John Matthewson to help him with supervising Physics undergraduates at Magdalene College. These early interactions with John Field inspired John Matthewson's career-long passion for teaching and Materials Science.

John Matthewson was the first of John's Ph.D. students to visit Luleå University (see next section) in the early 1980s where he set up a Laser Doppler Velocimeter and associated data-recording systems to observe the complex flow of water over a simulated shark's skin. Each of the small teeth shaped elements that make up the shark's skin were cast from a polymer resin. For many years afterwards, these facilities were in constant use and many Ph.D. students at Luleå were involved in fabricating the shark skin teeth for this interesting study. In those days, John Matthewson had a 1934 Austin Seven (as his only car) and whenever the Erosion by Liquid and Solid Impact (ELSI) Conference, chaired by John Field, was held in Cambridge, John Matthewson would ferry the US and other visitors from Churchill College, where they were staying, out to the Cavendish in it.

John Matthewson subsequently became a Professor of Materials Science and Engineering at Rutgers University where his research interests are mechanical performance of optical fibres, ceramic coatings and thin films, research topics of much interest to John Field [33–40]. John Matthewson is a co-author of a book entitled Mechanical Properties of Ceramics [41]. When he sent a signed copy to John Field, his only comment was that the book lacked coverage of diamond. This criticism should have been anticipated given John's interest in that material!

Luleå University of Technology, Sweden—SHPB, Liquid Impact and Other Research Activities

John Field had a very long friendship with Luleå University of Technology in Sweden (see Fig. 4). This started when Professor Martin Lesser became the first Professor in Fluid Mechanics and Professor Bengt Lundberg became the first Professor in Solid Mechanics, at Luleå University. John Field would often visit in March, when the weather was good for some skiing at weekends. From a young age, John was a very good runner and ran with the National Team. Following trips to Luleå, John also became an accomplished cross-country skier. For nearly 40 years, John had much influence on research activities at Luleå, and in honour of John's considerable contributions on experimental mechanical research over these years, there is now The John Field Laboratory for experimental mechanics research at the Luleå University of Technology (see Fig. 1 of John at the entrance of the laboratory in Luleå, named in his honour). Ph.D. students and Post-Doctorates would visit Luleå University with John and many of the research activities below grew out of the strong research links with Luleå University.

David R. Andrews, Director at Cambridge Ultrasonics Ltd, Ph.D. Awarded 1980—Erosion of Metals [43]

David R. Andrews arrived in Cambridge at the beginning of October in 1976 to study for a Ph.D. in the Fracture Group of PCS following some personal issues in his undergraduate time at the university of Bristol. However, he righted the

Fig. 4 Professor John Field OBE FRS, Cavendish Laboratory, University of Cambridge—long-time collaborator and Honorary Doctor at Luleå University of Technology (LTU), Sweden [42] (left) and LTU in winter (right)

ship and started a Ph.D. in Cambridge with John in 1975. David is very grateful for John's support during this difficult time and although, by his own account, he only got to study in the Cavendish in 1976 by the skin of his teeth and it was in a large measure due to John Field.

Once David arrived, John delegated his responsibilities for supervising David to a young post-doctoral worker called Ian Hutchings (PCS Ph.D. 1974 [2]), who eventually became a Professor in Engineering. Ian suggested David should do some experiments that were not too difficult, and whilst they occupied his time, they left him feeling rather like a rudderless ship apart from knowing he had to work on solid particle erosion of metals. With Ian moving to the Department of Materials Science and Metallurgy in 1977, David worked on the statistical nature of erosion and the effect of temperature on single and multiple particle impacts submitting his thesis in 1980.

When David arrived in Cambridge, he was given rooms in Selwyn College, staying in the same rooms for three years. He took the opportunity to participate in College activities: rowing, playing soccer and participating in the College's drama society. It was drama that led David to incur John's temper. David led a trip to the Edinburgh Festival Fringe with Selwyn's drama society and there was great excitement and enthusiasm as David found and reserved: excellent accommodation and a fine theatre in a school in Comely Bank. He even purchased an old ambulance from Girton Motors in Cambridge to provide transportation. David directed one of the three major plays that they performed and even acted in another. The group of 18 had a very enjoyable experience for three weeks in August and September of 1977.

Before leaving for Edinburgh, David ordered £500 worth of optical components for a secondary project. John was in the North of Sweden for several weeks when David was about to go to Edinburgh, so David ordered the essential optical parts before he left. When David returned from Edinburgh, he went to morning coffee to find virtually all the Fracture Group sitting around one table including John Field, which was unusual. They all wanted to know about David's adventures in Edinburgh so he related them but when David had finished, John spoke to him in front of the assembled members of the research group. "*Next time you order £ 500 of optical equipment without my permission and then disappear on holiday for 3 weeks—don't expect to return to complete your Ph.D*."—he then stood and left.

In 1994, twelve years after leaving Cambridge, David returned to live and work near Cambridge and after giving a seminar to the group, John asked that he refund the £500 he had spent 17 years earlier. David sent John a cheque of £100 every year thereafter until John said enough. David believes he repaid more than £500.

Towards the last 6 months of David's Ph.D. studies, he had built a substantial piece of equipment. It could perform single impact erosion tests and continuous erosion tests using sand or even the diamond grit as well as single ball bearings mounted on plastic sabots. The sample could be heated to 1200 °C and even cooled to − 100 °C using liquid nitrogen. Upon successfully defending his thesis, John generously provided a research fellowship for two years during which time David developed additional instrumentation for the solid particle erosion rig, notably a novel vibrating method for continuously measuring the mass of the sample during a continuous erosion test. David further developed the statistical theory of erosion to cover inter-particle collisions in the vicinity of an eroding surface. He also published several papers. The erosion rig David built is still in existence, albeit in modified form, and continues to be used up to the present by his successors in the Cavendish.

Sybrand van der Zwaag, Professor of Novel Aerospace Materials, TU Delft, The Netherlands, Ph.D. Awarded 1981—Strength and Impact Properties of IR Transparent Materials [44]

The experimental and computational research on liquid jet impact initiated by John Matthewson was continued by Sybrand van der Zwaag [45, 46]. Sybrand got this topic allocated to him during his very first meeting with John Field, who after some pleasantries posed the question to his very fresh Ph.D. students Chris Freeman and Sybrand "*Which topic would you prefer: diamond fracture or liquid jet impact on IR transparent ceramics?*" Both Chris and Sybrand were taken by surprise and could not utter anything more than "*Uhhh…*" John, with his characteristic high speed in decision making, then said "*Well we are not going to wait for this. Chris you do diamonds and Sybrand you do jet impact! Please read into the literature and come back to talk to me next week on details*." And so, both our careers started.

Looking back to his time working with John, Sybrand will always remember John's speed and precision as well as the diversity of his interests in applied science/physics, but also his commitment to his students, irrespective of their talent. He would guide and expect results to be delivered, but at the same time would also allow and stimulate students to work on new topics and to propose new strategies. He did not micromanage his students and they always felt safe and secure to play croquet on the lawn under his office windows on sunny days, knowing that if he needed them then and there, he would open the window and shout out, but would never hold it against them that we were wasting valuable research time. This freedom made them work hard and with great creativity and deliver results to the best of their abilities. While Sybrand certainly learned a lot on the scientific aspects of his research topic, he thinks John's talent for academic leadership has had the biggest impact on his career. John's ability to decide and act fast, to make sure that lack of funds was never an issue, that his students felt challenged and supported, and that a proper research policy would involve some long-lasting research lines as well as some shorter-lived side-lines, were lessons Sybrand shares he has never forgotten.

After completing his Ph.D. project, Sybrand, his wife Emma and their two young daughters returned to the Netherlands to take up a post-doctoral project on amorphous metals after which he joined AkzoNobel to work as a physical chemist on the development of liquid crystalline polymer fibres. In 1992 Sybrand was appointed full professor at the TU Delft where he built a new research group on Microstructural Control in Metals. In 2003 he started a new research group at the TU Delft working on Novel Aerospace Materials, where he could combine his interests in ceramics, polymers and metals and lead the national and international research on Self-Healing Materials. In the 40 years of his post PCS research career, he always remained grateful to John Field for the numerous wise lessons graciously given during his Ph.D. time.

Stephen M. Walley, Research Associate, Cavendish Laboratory, University of Cambridge, Ph.D. awarded 1982—Erosion of Polyethylene by Solid Particle Impacts [47]

Stephen Walley first met John Field in 1977 when he was a final year Physics undergraduate at the Cavendish Laboratory, University of Cambridge, doing a research project in John's group under the supervision of Munawar Chaudhri on the impact of small steel spheres on glass. For this project Stephen (along with two other final year students, Adrian Stephens and Patricia Brophy) got to use the group's Beckman & Whitley 189 rotating mirror high-speed camera, the same one that John Field had used in his Ph.D. back in the early 1960s [1, 48]. The 189 has a maximum framing speed of 4×10^6 frames per second. In order to achieve that framing rate, the helium-driven turbine has to be spun at 16,000 r.p.s. Since it would be catastrophic if the turbine were to fail at that rotation rate, they were under strict instructions not to exceed 4,000 r.p.s. This limited the framing rate to 1×10^6 frames per second. Stephen was very fortunate that the students with which he did the project were much more confident experimentalists than he was at the time. All three projects led to papers being written and published by Munawar Chaudhri [49–51]. The 189 is now in the Museum of the Cavendish Laboratory.

Towards the end of Stephen's final undergraduate academic year, Munawar Chaudhri introduced him to John Field as a potential Ph.D. student. John Field recommended Stephen do a Masters at Bristol University on the Physics of Materials. This was a full one-year programme, the first half consisting of examinable lectures, the second half being a research project. Stephen had a very happy 12 months in Bristol during which his experimental skills improved. He then returned to Cambridge in the Autumn of 1978 to work under John Field's supervision on the solid particle erosion of polyethylene, a project which the British Gas Corporation funded as they were worried about the migration of rust and dirt from their old cast iron pipe network into their new polyethylene gas-distribution system.

When Stephen started, Ian Hutchings and others had recently developed laboratory gas-guns for the Physics and Chemistry of Solids (PCS) group that could fire spheres and square plates at velocities between around 40–300 m s^{-1} [12, 52]. So, Stephen's initial studies on behalf of the Gas Corporation were on the impact of single particles, which he managed to capture using a Hadland Image Convertor Camera that John Field had recently obtained for the group (Fig. 5). But, of course, the engineers at British Gas were really interested in what happens when many small particles impact a surface in quick succession. Fortunately for Stephen, a post-doc in John's group, David Andrews (Ph.D. 1980 [43]), was designing a rig to do just that [53]. His erosion rig therefore enabled Stephen to complete a thesis to their satisfaction by 1983 [47], a summary which was published a few years later in the Philosophical Transactions of the Royal Society [54].

During the course of Stephen's doctoral studies, he came to understand that the mechanical properties of polyethylene he was studying depended on how rapidly it is deformed. So, it made sense to accept a post-doctoral position that John Field offered him to investigate strain-rate effects in a number of different polymers that were being considered as replacement materials for the soft metals used in driving bands that spin up shells as they are accelerated up rifled gun-barrels [55–57]. Again, Stephen was very fortunate to be joined by two people John Field had attracted to the group (Peter Pope (Ph.D. 1984 [58]) and Nick Safford (Ph.D. 1988 [59])) who had taken over the miniaturised direct impact Hopkinson bar (3 mm diameter) previously developed by David Gorham [60]. So, at the time Stephen started this project, like most groups that performed high-rate testing, they were only able initially to obtain stress–strain curves at very low rates of strain (10^{-3} s^{-1}) and very high rates of strain (10^{+3}–10^{+4} s^{-1}) [61, 62].

After that project was finished, Stephen heard that at Loughborough University (where Gerry Swallowe, a former student (Ph.D. 1979 [63]) and post-doc of John Field's had moved to) there was a hydraulically operated mechanical testing machine that could generate data at intermediate strain rates (1–30 s^{-1}). This led to Stephen to work on the Loughborough campus for two weeks to obtain this data. He found that plots of the yield/flow stresses against log(strain-rate) lay on a straight line for a wide range of polymers up to about 10^{+3} s^{-1}, which was very pleasing (Fig. 6). Although John Field and Stephen published the data in the short-lived DYMAT Journal [64], this has been one of Stephen's most-cited publications.

Before Gerry Swallowe left Cambridge, he had trained Stephen in the use of the C4 rotating mirror camera (Fig. 7), one of which had been given to the PCS group by the Atomic Weapons Establishment a few years after the Partial Nuclear Test Ban Treaty of 1963. The C4 camera had been designed at AWE in the mid 1950s for obtaining high-speed photographic sequences of nuclear bombs exploding in the atmosphere [65]. The C4 camera had the capability of taking 140 photographic images with a 5 μs interframe time with still camera resolution (Fig. 8), although for safety reasons the group almost never ran it faster than 7 μs interframe time. Again, Nick Safford and Peter Pope were amazingly helpful during the year or so that it took to bring the optics of the camera into the condition where images such as those shown in Fig. 8 could be obtained.

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 as the pixels in CCDs were still larger than the silver grains

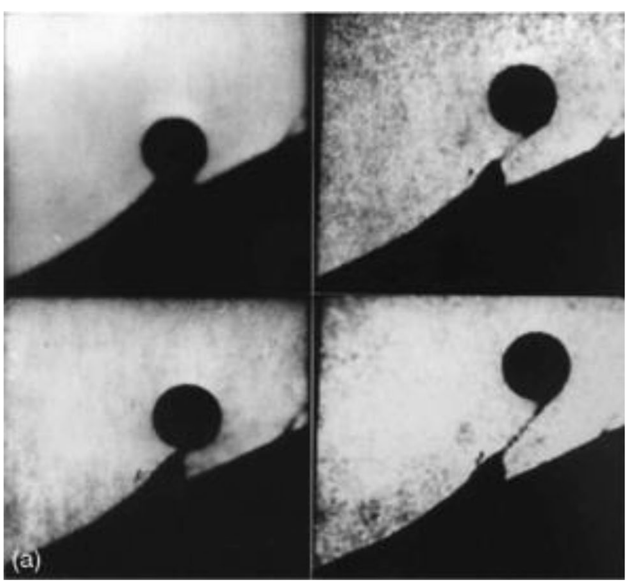

Fig. 5 Selected frames from a high-speed photographic sequence showing the pulling out of a filament of polyethylene caused by the impact of a 4 mm diameter steel ball at 190 m s^{-1} at 25° impact angle. Interframe time 19 μs. From [14]

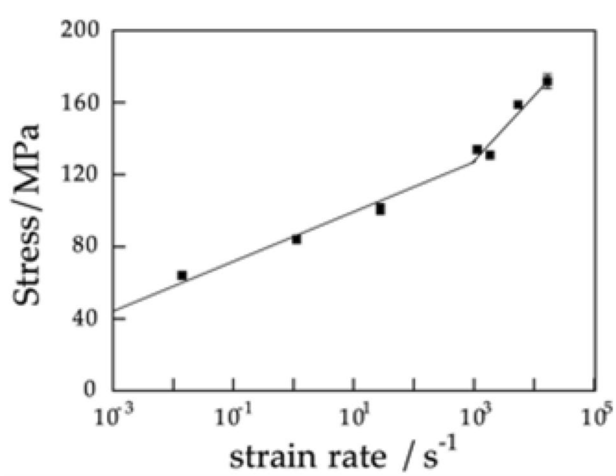

Fig. 6 Plot of the flow stress as a function of strain rate in uniaxial compression for PVC. From [64]

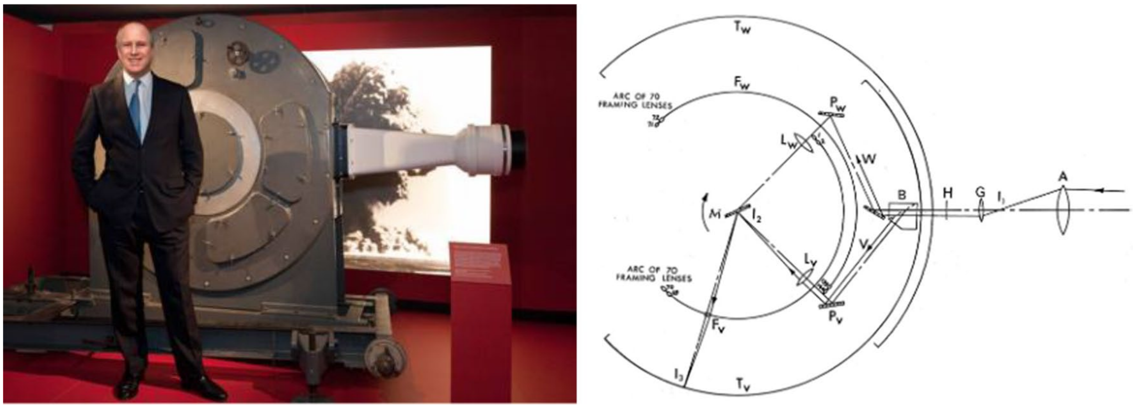

Fig. 7 (left) Randolph Churchill (Winston Churchill's great-grandson) standing in front of our restored C4 camera in the Science Museum, London [66]. (right) Schematic diagram of the internal optical workings of the C4 camera. For more details about this machine, see [65]

on black and white negative film [67]. However, since electronic cameras are much easier to use (and much smaller!) than rotating mirror cameras, in 2012 the group gave their C4 to the permanent collection of the Science Museum in London, who restored it and put it on show for 15 months starting in January 2015 as part of an exhibition entitled 'Churchill's Scientists' (Fig. 7).

From around the mid-1990s, John Field's group was equipped with the techniques that Stephen was to use until his retirement in 2014, namely light gas guns, the glass-anvil drop-weight, split Hopkinson pressure bars and high-speed cameras. This led to Stephen publishing a series of research papers with John on topics as diverse as the impact ignition of propellants and PBXs [68, 69], explosive powders [70, 71] and the high rate properties of metals investigated using Taylor impact [72–74] and split Hopkinson pressure bars [75].

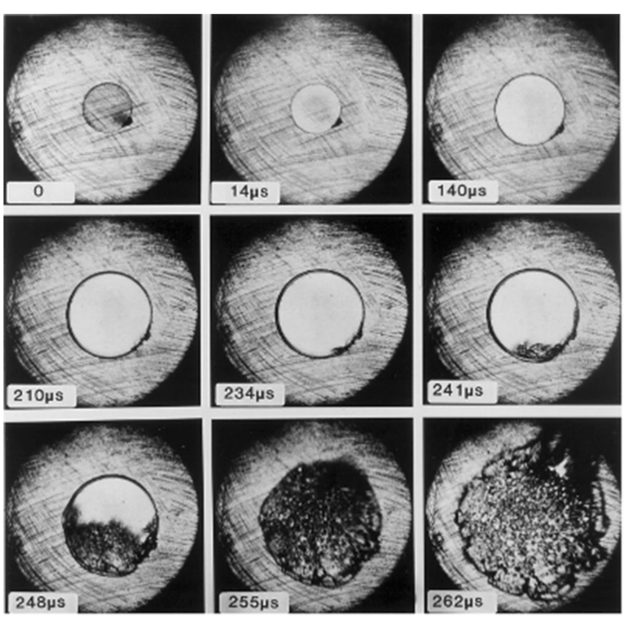

Fig. 8 Selected frames from a high-speed photographic sequence of a 1 mm thick, 5 mm diameter polycarbonate disc being deformed between glass anvils in a dropweight machine. The streaks around the disc are petroleum jelly lubricant. From [61]

Stephen had always read widely in the published literature for any research project John Field introduced him to. So, John was also able to sell Stephen's services to sponsors of research to perform literature reviews on subjects they were interested in. This has led to Stephen to writing a number of published research reviews on a wide range of topics including: experimental methods at high rates of strain [76, 77], elastic wave propagation in materials [78, 79], impact sensitivity of explosives [67, 80], shear localization [81, 82], indentation hardness [83] solid particle erosion [14], and the high rate properties of ceramics [84] and glasses [85]. This set Stephen up well for his retirement where he has continued to write historical reviews on various topics to do with the high-rate mechanical properties of materials [86–92].

Chris J. Freeman, Technical Director GaffneyCline, Ph.D. Awarded 1984—Strength and Fracture Properties of Diamond [93]

John Field was also heavily involved with diamond research and had several Ph.D. students researching the topic, including Chris Freeman. John edited two books on the properties of diamond [94, 95] and organized many of the annual diamond conferences in Cambridge, Oxford, Reading and Royal Holloway. Chris's Ph.D. with John focused on the strength and fracture properties of diamond [96] and Chris also worked with John Field and David Tabor on the friction properties of diamond [97].

John was incredibly good at securing research funding from a host of sources and very effectively managed the expectations and needs of the funding organizations which included US and UK Military establishments as well as private companies. John followed in the footsteps of Philip Bowden and David Tabor, especially with regard to the importance of ‘simple’ direct experimental design and the capability to research and solve real engineering problems as well as perform high quality fundamental research.

John led and managed a unique group of research staff and we all recall that morale was always high. John’s ‘Fracture Group’ also provided significant input to the annual PCS cabaret, the Cavendish Boat crew and the Croquet team. Chris shared “*we all know that many of our colleagues and peers thoroughly enjoyed our time in the Group and look back with very fond memories*”.

John P. Dear, Professor of Mechanical Engineering, Imperial College London, Ph.D. Awarded 1984—The Fluid Mechanics of High-Speed Liquid/Solid Impact [98]

John Dear is now a Professor at Imperial College London and his Ph.D. research interest was high velocity liquid impact [99–101] and cavitation [102, 103]. Much of the experimental research published came from research performed by John Dear, John Field and Martin Lesser at Luleå University of Technology and Cavendish Laboratory. John Field and Martin Lesser had suggested that by adding gelatine to water it should be possible to perform two-dimensional impacts of a liquid drop and other liquid shapes to visualize shock wave generation, jetting and related processes (see Fig. 9).

This technique could also be applied to cavities collapsed by a shock wave and the interaction of the shock wave to form a jet and subsequent collapse of other cavities could be visualized (Fig. 10). John Field was very good at describing this research in a lively and interesting way when giving lectures or entertaining visitors at the Cavendish Laboratory. He would often finish with a story or two of their escapades on the cross-country ski tracks through the forests around Luleå. John liked to tell the story of how on one occasion, a dog sled was coming towards us. John would say: “*The dogs went on one of side of John Dear and the sled on the other, and you can imagine what happened*.”

In recent times, John Dear has focussed on impact damage of laminated glasses and composites, a topic of much interest to John Field [104–106]. John Dear very much enjoyed his Ph.D. days at the Cavendish Laboratory supervised by

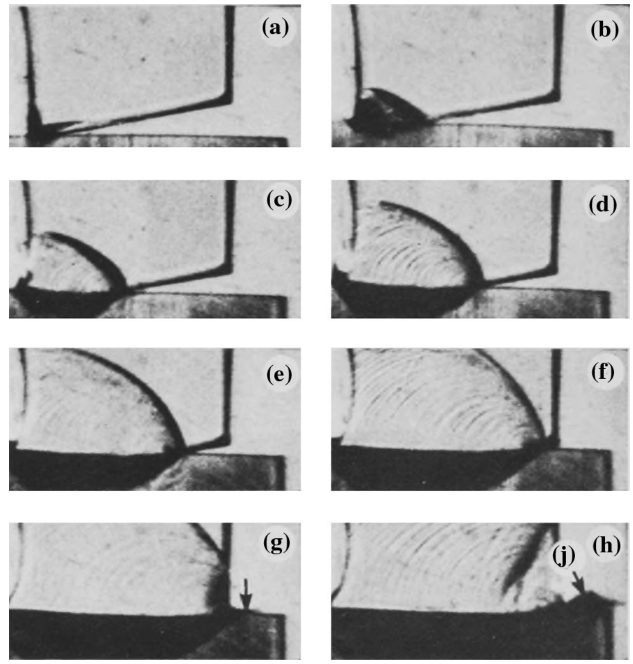

Fig. 9 Liquid impact (at 150 m s^{-1}) using the two-dimensional gelatine technique. From [99]

John Field and when he left to join Gordon Williams and Tony Kinloch at the Department of Mechanical Engineering at Imperial College, John Field, who was always very competitive, reminded me that the Cavendish were the first to discover hot crack tips!

David Townsend, Senior Research Fellow, Rolls-Royce University Technology Centre, University of Oxford, Ph.D. Awarded 1985—Liquid Impact Properties of Brittle Materials [107]

Underpinning interest in liquid impact, was research by David Townsend, formerly Senior Research Executive, BAE Systems and now Senior Research Fellow, Rolls-Royce University Technology Centre, Oxford University. David’s research was focussed on liquid and solid particle impact damage to ceramic materials used in the aerospace industry. The characteristic circumferential cracking (see Fig. 11) is unique to liquid impact and was often described by John Field to visitors, when they came to the Cavendish Laboratory. There was usually a lunch for the visitors at a nearby pub in Coton village. John would often say, “*We will go in David’s car*”. The US visitors would look at each other and think how they were all going to fit in a small UK car. They

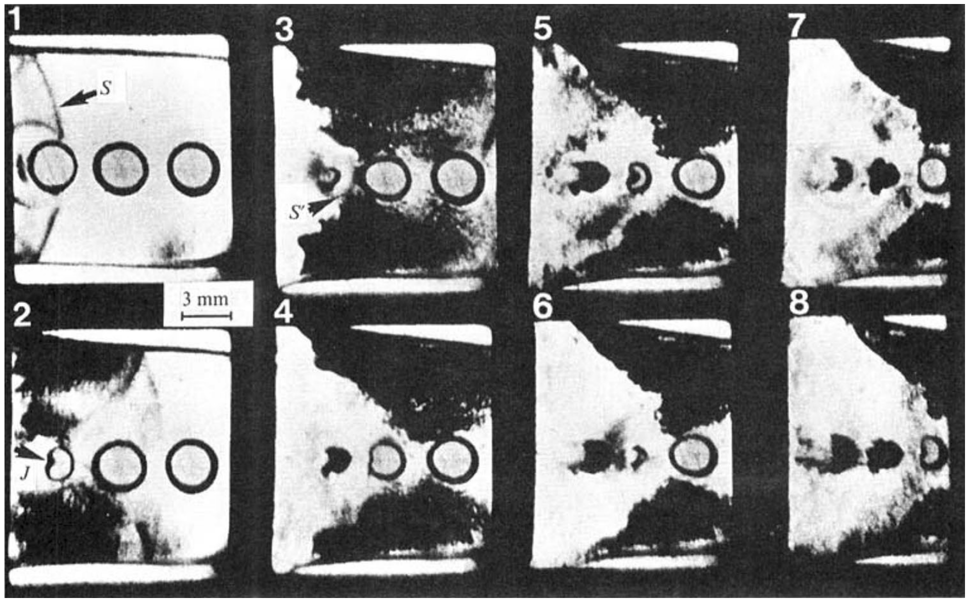

Fig. 10 Cavity collapse with the two-dimensional gelatine technique of 3 mm diameter cavities collapsed by a 0.3 GPa shock wave. From [102]

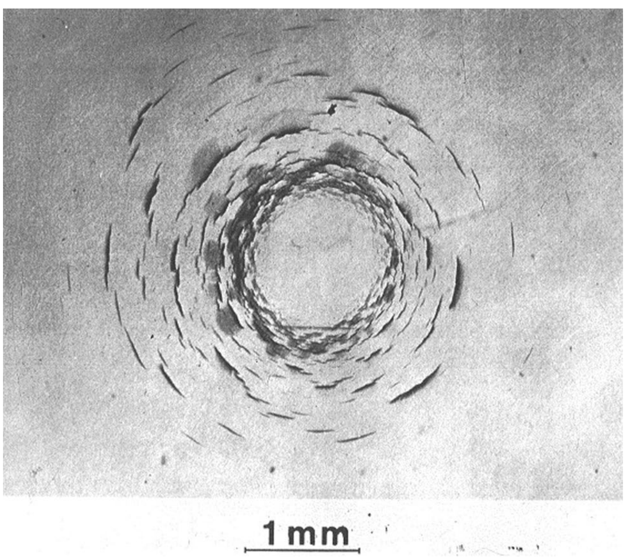

Fig. 11 Liquid drop impact damage site on zinc sulphide. From [107]

were always pleasantly surprised when we walked into the car park to get in David's Saloon Jag.

In recent times, David Townsend's research has focussed on high-rate split Hopkinson pressure bar (SHPB) testing of engineering alloys, a topic of much interest to John Field [108, 109]. David very much enjoyed his Ph.D. with John Field and went onto to set up a state-of-the-art two stage light gas gun capable of launching projectiles in excess of 4 km s^{-1}, at the BAE Systems Sowerby Research Centre in Bristol [110].

Jonathan M. Huntley, Professor at the School of Mechanical, Electrical and Manufacturing Engineering, Loughborough University, Ph.D. Awarded 1987—Laser Speckle and Its Application to Strength Measurement and Crack Propagation [111]

Jonathan Huntley first met John in 1983, when John lectured a final year course on materials. John preferred traditional 'chalk and talk' to the overhead projectors used by most lecturers of that era, with a distinctive left-leaning handwriting that was difficult to follow at times. But he gave valuable physical insights into the more abstract concepts and brought the subject to life. Jonathan also caught glimpses of what he realised later was a great sense of humour, often dry and with such a deadpan delivery you were not always sure if he was joking or not—for example, "*I've now seen this year's exam paper, and all I can say is I'm glad I'm not taking it*". Jonathan had a keen interest in photography, particularly the freeze-frame photography of insects in flight pioneered by Stephen Dalton [112]. After visiting John's 'Fracture Group' Lab on the ground floor of the Cavendish (to a cash-strapped student, this seemed like an Aladdin's Cave of high-speed photographic equipment), Jonathan decided to accept John's offer to do a Ph.D. with him.

As mentioned elsewhere in the paper, John and his predecessors in the PCS Group had assembled an impressive array of high-speed cameras, but in the late 1970s he realised that information on displacement and strain fields would be needed to quantify fracture phenomena such as the stress intensity factor at the tip of a running crack. He invited Prof Fu-Pen Chiang (State University of New York) for a one-year sabbatical to the group. Fu-Pen is an expert on experimental mechanics techniques such as moiré and speckle photography.

John together with long-standing Fracture Group member, Stuart Palmer, initially adopted laser speckle for quantifying the mechanical properties of polymer bonded explosives undergoing quasi-static loading. The 'Brazilian' test geometry (diametral loading of a small disc) allowed measurements on small amounts of material (an essential requirement from a safety perspective), and laser speckle, as a non-contacting technique, avoided errors due to strain gauges debonding from, or reinforcing, the explosive samples [113].

John's idea for Jonathan's Ph.D. (1983–1986 [111]) was to extend the laser speckle work to the high-speed cameras, to capture the dynamic displacement fields associated with impact and fracture events. This involved two main challenges: firstly, how to analyse the large number of fringe patterns (typically hundreds or thousands) associated with each speckle photograph, and secondly how to achieve sufficient laser power on the target to expose film when recording at up to one million frames per second. For the first challenge, Jonathan proposed building an automated system, based around the new readily available microprocessors (the BBC Micro had just appeared). John was initially reticent as he felt that integrating a computer into a test rig risked introducing months of delays, but went along with the idea and was very supportive throughout. For the high-speed work, his suggestion was to use a rotating mirror camera (the Beckman and Whitley 189) and a pulsed ruby laser that was lying idle in the lab. The laser, with its water-cooling unit springing leaks at regular intervals over an impressive bank of high voltage capacitors just below, would not be allowed in today's health and safety climate, but by introducing a Pockels cell Q-switch into the laser cavity, and a set of photodetectors in the camera, we were finally able to achieve the long-term goal [114]. Along the way, they also investigated the use of multiple exposure speckle photography to record time-varying displacement fields without a high-speed camera [115], proposed the use of the J-integral to extract stress intensity factors from experimental displacement field data [116], and developed a high-resolution version of traditional moiré photography [117], which provided sub-micron displacement resolution at microsecond framing rates (Fig. 12).

Following his Ph.D., from 1990–1993 Jonathan accompanied John on four occasions to Luleå University in the far north of Sweden, where John had a well-established collaboration with the group led by Professor Nils-Erik Molin. John chose the time well—always the Easter vacation, when temperatures were still low enough to guarantee excellent skiing conditions, and evenings were already light enough to make full use of the cross-country trails in the nearby forests. John had a 'work hard, play hard' approach to life there—after an 8am start, he would typically be doing gas-gun impact experiments through the day with Allan Holmgren, while Jonathan was in one of the interferometry labs. At about 4 pm he would wander over, suggesting it was 'time for a bit of exercise'.

The 'bit of exercise' would consist of a circuit round the 5 km or 10 km ski trail just off the campus. Jonathan had never been on skis before his first visit. John explained the basics very well (though he was never fully au fait with the elaborate system of waxes for the different temperature ranges), and always waited patiently for Jonathan at each fork in the trail as he struggled behind in John's wake. Jonathan never managed to go as fast as John, despite the near 30-year age gap, but for one exception: Professor Håkan Gustavsson one weekend took John and Jonathan onto a frozen lake and taught them how to skate with cross country skis. This technique allows one to cover distance much more efficiently on flat ice than with the classic 'parallel ski' method, but requires careful coordination and angling of the skis that John was not always comfortable with. They made use of their new-found skills on many wonderful day

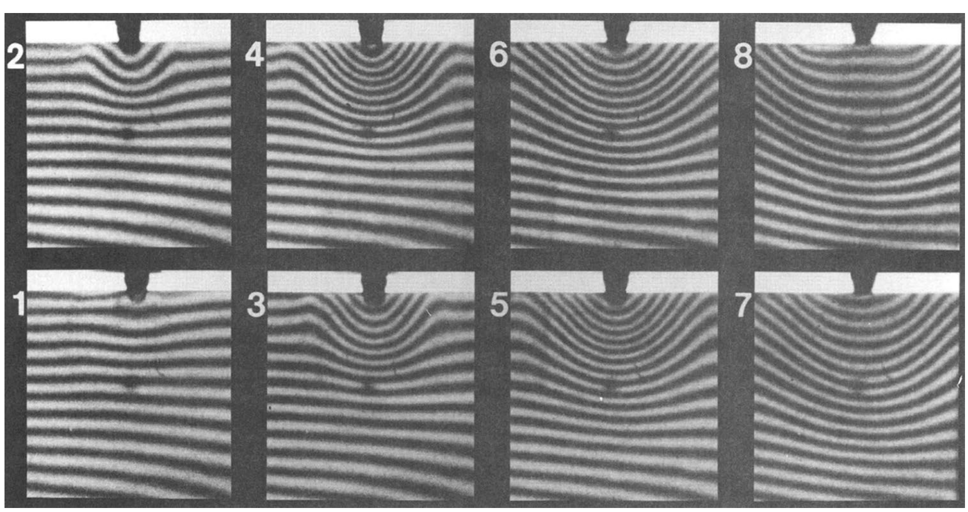

Fig. 12 High-speed photographic sequence of the deformation of moiré fringes produced by the impact of a 2 mm diameter steel ball on PMMA at 115 m s^{-1}. Interframe time 0.95 µs. Field of view 16×16 mm^2. From [117]

visits to Nils-Erik's summer cottage on the edge of the Luleå archipelago. They would eat waffles on the terrace, then ski across the frozen sea to one of the nearby islands, sometimes with Nils-Erik's daughters, Elisabeth and Johanna, wife Eva, and always with his hunting dog, Rita (Fig. 13). Supper would be reindeer or other wildlife caught by Nils-Erik and Rita. Post-supper conversation was diverse: music, Swedish history, economics, family. John and Nils-Erik also introduced Jonathan to the black humour of Tom Lehrer songs ("*we will all fry together when we fry*", etc.) which amused them greatly as they sang through them from memory. It was truly "*back to nature*", and John summarised it on one occasion with the verdict: "*one of the five best days of the year*".

Dr Lars Benckert and his wife Inger were also very generous in inviting Jonathan and John to their home for dinner on numerous occasions. After dinner, John would read bed-time stories from books about tractors or lorries to their young son Martin (aged three on their first visit). Martin always struggled to understand the mangled Swedish, but was too polite to complain. Other memorable outings included one to Allan's summer house where they spent several hours fishing through a small hole in the ice, with no success. At the end of each stay, John would invite all the people who had been so kind to them to a meal at a local restaurant. He and Ineke were also hospitable hosts, inviting overseas visitors, researchers and colleagues to their Cambridge home on many occasions.

Before Sweden, if Jonathan had had to summarise John's character in a few words, he would have said: hard-working, intelligent, competitive, conservative. The Swedish trips revealed to him other sides to his personality: kind, humorous, cultivated, sociable and generous.

Jonathan commented that John was an ideal Ph.D. supervisor: "*he sketched the outlines of the big picture, and provided all the paints Jonathan requested, but left the detailed brushstrokes to me. He was no backseat driver*".

Fig. 13 Photograph taken by Jonathan Huntley in 1992 at Luleå of John Field (right) with Professor Nils-Erik Molin (left)

He emphasized the importance of publishing; before the first visit to Luleå, his advice was to do the experiments and write them up before the returning home—something Jonathan aspired to each time, though never quite managed.

The group he led was focussed on the applications of physics, which meant regular meetings with, and presentations to, the 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 of the Fracture Group 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. He provided excellent advice to Jonathan when he was applying for his own funding, which led to research fellowships from the Science and Engineering Research Council, Gonville and Caius College, and ultimately the Royal Society, all of which Jonathan held in John's group. The experiences from those early years, the shelter from excessive routine teaching too early on, and the opportunity to co-supervise talented research students (Tim Goldrein and Martin Whitworth) proved to be invaluable preparation for Jonathan's own academic career: he was offered a readership at Loughborough University at the age of 32, and promoted to a personal chair five years later. Jonathan relays that all of his subsequent research activity over the past 26 years, from laser measurements of biscuit fracture to 3D vision systems for robots, has been shaped in some way by those formative years in John Field's group.

Timothy G. Leighton, Professor of Ultrasonics and Underwater Acoustics, University of Southampton, Ph.D. Awarded 1988—Response of Gas-Filled Cavities to Acoustic Field [118]

In 1984 John Field's interests extended to the acoustics of bubbles with an undergraduate project by Timothy Leighton on the sound produced by gas bubbles when injected into liquids, co-supervised with Alan J. Walton who had just arrived to the Cavendish from the Open University. John and Alan supervised a second undergraduate, Hugh Pumphrey, and they adapted the techniques to study the sound of rainfall over oceans, whilst, under the co-supervision of John and Alan, Leighton moved from the sounds made by bubbles, to the effects that various forms of medical ultrasound (e.g. physiotherapeutic, foetal imaging) could have on bubbles, and whether this might produce desirable or undesirable effects on tissues [119–121]. Although Leighton left the Cavendish in 1992, John and he stayed firm friends for the rest of John's life, continuing in the 1990s their joint trips to Lausanne, and corresponding and exchanging papers until 2019 [122].

John's trips to the Laboratoire de Machines Hydrauliques at École polytechnique fédérale de Lausanne (EPFL) in Swtizerland were a feature of many summers in the 1980s and 1990s. Ostensibly to study cavitation from the cavitation tunnel there—including the first detection of sonoluminescence from undoped water, in an experiment with Timothy Leighton in collaboration with EPFL's Mohamed Farhat and Francois Avellan—the trips were also an opportunity for John to indulge in his love of mountain walking. On a trip with Tim Leighton and EPFL's Sadi Ridah, the three aimed to be the first in the climbing season to reach the top of Rochers de Naye using the Grottes de Naye, a cave system through the upper half of the mountain. This entailed climbing to the approximate entrance to the caves, then finding that entrance in the trackless, snow-covered face of the mountain, then breaking through the snow and entering the mountain. Having successfully climbed the upper portion of the mountain from the inside to the summit, rather than on the side of the mountain on which they had left Sadi's car, the three descended halfway down the far side and, at John's insistence, ran through the train tunnel that goes through the heart of the mountain, John asserting the feat would be possible if they started just after a train emerged from the tunnel, because of the accuracy by which Swiss trains kept to their timetable. Once they started, they found the construction rubbish strewn along the pitch-black tunnel slowed their run, but nevertheless they completed it in time, the only mishap being Sadi's car brakes, which became so overheated on the descent that they visibly glowed in the night, and the team had to blow mouthfuls of water down straws onto the brake pads to cool them. Cohabiting with John, running and trekking with him on these trips, revealed the depth of his sense of humour and love of fun, and showed that whilst on the surface his smiles (though not infrequent) were not large, they covered a profound ability to see the amusing side of things.

Neil K. Bourne, Professor of Matter in Extreme Environments, Department of Mechanical, Aerospace & Civil Engineering, the University of Manchester, Director of The Thomas Ashton Institute, Director of The University of Manchester at Harwell, Ph.D. Awarded 1990—Shock Wave Interactions with Cavities [123]

Neil Bourne's association with John began when John attended Neil's Cambridge interview in Magdalene in 1983. That was the start of a long relationship that spanned Neil's time at the university, starting with John being Neil's supervisor for his degree, then as John's Ph.D. student, within the 'Fracture' group, and on to a research fellowship in Clare Hall. Finally, John helped Neil return to a fellowship in Magdalene as he started the shock physics group within the Physics and Chemistry of Solids group (PCS). Neil's research straddled several research areas, each with shock waves as their driver. First through interest from Marty Lesser (Luleå) and Francois Avellan (Lausanne) on cavitation and the erosion of solid surfaces attacked by cavities. A common approach to understanding behaviour followed a method developed by John Dear who demonstrated that a cavity punched into a confined sheet could be collapsed under a weak shock. A second strand was research on explosive ignition by bubble collapse, stretching back to the pioneering work of Bowden and Yoffe who showed the importance of localised hot spots in starting a reaction in an energetic material (Fig. 14). Finally, the work on solid and liquid impact had equipped the lab over the years with several small launchers capable of firing projectiles at surfaces where erosion, pitting or fracture could be studied and where

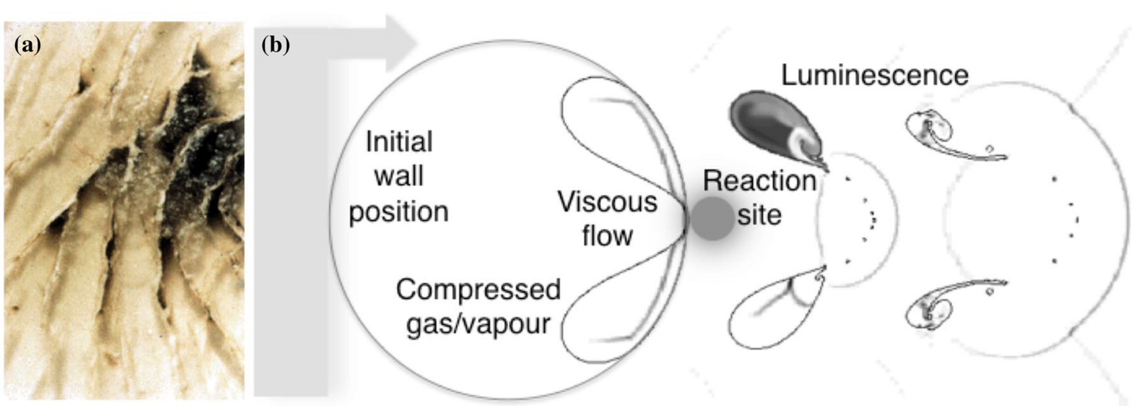

Fig. 14 Hot spot ignition; **a** shear banding in HMX [124], **b** shock-induced cavity collapse in high explosive [125]

shocked states could be observed as materials were loaded. Neil's Ph.D. focused on the collapse of bubbles added or entrained within solid explosives. The problem was posed by Nobel's Explosives, where at the division of ICI based in Ayrshire, and Neil spent many wet Scottish winters doing experiments in bunkers. There he drove bubbles in explosives to collapse with a detonating charge, returning to shock inert analogues with a laboratory gun in Cambridge. John never ventured north during Neil's time there, choosing the snow of Sweden rather than the rain of Scotland.

Throughout Neil's research (and surely in that of others) it became clear that equipment in the Cavendish limited the amplitude of the impulses that could be generated and the size of projectiles that could be launched. However, in 1990, a visitor from the RAFAEL laboratory in Israel—Zvi Rosenberg—arrived for a sabbatical. Zvi's work resonated with equivalent interests from groups at the DRA Fort Halstead and Chertsey laboratories. John wove his magic and brought together sponsor problems, funding and visiting expertise. Neil's background in shock and launchers allowed him to build a new facility and founded a shock physics group within PCS. Further, a launcher capable of precise, one-dimensional shock loading was built, the first of many Neil then constructed across the UK. The facility was operational within a year, and Neil will always be grateful that John was so generous in allowing a new speciality to prosper alongside his existing areas. Indeed, John supported Neil's bid for a series of lectures on Shock Waves and Explosives, which was accepted, written and delivered to fourth year students. Other visitors followed including Rusty Gray from Los Alamos, who joined PCS on sabbatical expanding the shock physics group's interests and growing our capabilities. At the same time Peter Dickson was developing his work on ignition into studies of full detonation, again expanding capabilities to access more extreme environments and problems.

Shock physics in those early years spawned streams of work across a range of metals and polycrystalline ceramics. A particular interest of Rosenberg was the shock response of glass and particularly in the unexplained fracture wave following an elastic shock, first observed by Kanel [126]. The failure of a metal, in the weak shock regime at least, can be thought of as a shock front following an elastic precursor wave taking the material to its higher stress plastic state via slip and twinning. Experiments on glasses, however, showed evidence of wave reflections from propagating damage fronts behind the elastic front that indicated a delayed drop in shear strength behind it within the elastic range [127]. We were able to confirm these inferences using embedded sensors and simultaneous high-speed streak and framing photography which unequivocally showed the process of failure occurring in the compressed material (see Fig. 15a).

The failure process can directly be imaged in the glasses under shock. Figure 15a shows a flyer plate (above the frame) hitting soda-lime glass where failure is initiated at the impact face and the shock, driven from the top can be seen travelling down the target. The fracture front passes down the block behind the shock which appears as a dark bar, at higher stresses it travels faster until at a critical stress level, failure occurs in the front. When first detected by Kanel these fronts were known as *fracture waves*. However, they are better dubbed *failure waves* since similar fronts observed in polycrystalline ceramics for instance have some ductile component.

If the longitudinal and lateral stress components are measured in a glass block as it is loaded, the effects of propagating fracture fronts become apparent as losses in strength. Figure 15b shows the recorded stress levels at a sensor in the flow and in the direction of, and perpendicular to the shock travel. The shear strength history shows a drop in the strength of the glass behind the front. Whilst these histories were obtained from soda-lime, similar behaviour is also observed in other glasses that have been examined in this stress regime. The locus of the unfailed and failed strengths, shown in Fig. 15c demonstrates that shear strength levels are

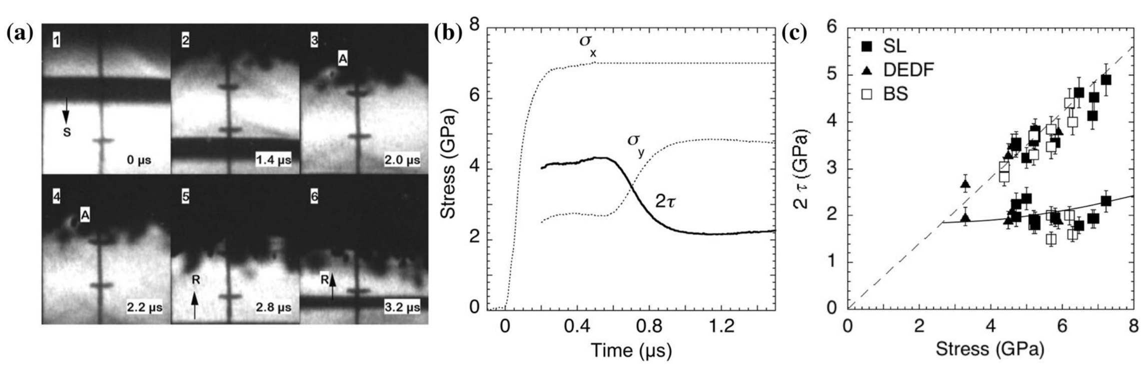

Fig. 15 **a** High-speed photography of soda-lime glass (shocked from above). **b** Components of the stress field measured at a station 3 mm from the impact face in soda lime glass below the WSL. **c** Strength data in the initial elastic and the final inelastic states for the three glasses; soda-lime (SL), DEDF—a lead glass and borosilicate (BS) [128, 129]

similar for the three glasses, remarkable since density for instance varies from 2.2 to 5.2 g cm^{-3} amongst them. This shows strengths to be governed by the amorphous silicate network that bonds the materials together—a result ahead of equivalent work in other laboratories at the time.

Forming a shock physics group extended the range of strain-rates and controlled the precision of the loading that might be applied at the Cavendish. Previous studies of materials were based around drop weight and split or direct Hopkinson bar work already in progress. With Peter Dickson then extending the classic hot-spot heritage to include studies on detonation and laser initiation, the reach of the physics studied was expanded and enriched (Fig. 16). Yet in the end, the space available within the crowded Cavendish limited the size of the launchers that could be constructed and the quantity of explosives that could be initiated. This thus constrained the range of problems that could be studied. Thus, a suite of larger launchers including a two-stage system for more extreme states and the capability to shock hundreds of grams of high explosives, were built in a parallel laboratory at the Royal Military College of Science in Shrivenham. Neil remembers John visiting to see the laboratory on his annual trip to Oxfordshire, examining the three large launchers then operational and commenting on the luxury of space and the ability to fire quantities of explosive that we had on that site.

With the legacy that John and his students have continued, John has assured a cadre of experience exists both in the UK and in other universities and national laboratories overseas where supervisees are now working. The mix of subjects studied, and techniques fielded was always varied and eclectic, but it was that heterogeneity, coupled with the freedom that John permitted, that allowed his students the freedom to innovate and create. His outreach to funding agencies brought a unique mix of industrial, government laboratory and research council funding and in many ways, the group's great strength was that it was multidisciplinary before multidisciplinary became de rigueur.

From the time John inherited Philip Bowden's cross-disciplinary group, and up to his retirement, John Field acted as a research beacon for Cambridge's high strain-rate research. The period of rationalisation in national establishments, and changes of emphasis in research, that occurred during his tenure moved physics towards nanoscale, biological and quantum problems, and away from multidisciplinary, macroscale research. Nevertheless, at a time when cross-disciplinary, applied research is an increasing focus for funding councils, the Fracture group's diverse range of problems and cadre of high-quality cross-disciplinary students, is model for research that is now being recreated. Finally, whilst John never spent as much time in the college as some, Neil shares, "*John is remembered whenever I visit, and I shall toast his memory when I next return to Magdalene to remember his achievements and thank him for the formative assistance he gave me*".

Peter Dickson, Group Leader, Los Alamos National Laboratory, Ph.D. Awarded 1990—Fast Reaction in Primary Explosives [131]

Explosives research at the Cavendish dates back to World War II, when Philip Bowden and one of his students, Abe Yoffe, temporarily stationed in Australia, started working on explosive initiation mechanisms related to explosive accidents, studying, in particular, how reaction is started by non-shock impacts and other mechanical stimuli such as friction [132]. This was a natural extension of Bowden's work with David Tabor on the physics of the frictional interaction between solids [133], and directly led to the seminal theory that all explosive initiation processes are fundamentally due to localized thermal hot spots.

After returning to Cambridge after the war, they continued to work on explosive initiation, including frictionally induced hot spots [134, 135], branching out to include both primary and secondary explosives, initially in the Department of Physical Chemistry but later forming what became the Physics and Chemistry of Solids Laboratory (a.k.a. PCS) in the Department of Physics. John Field joined PCS in 1958

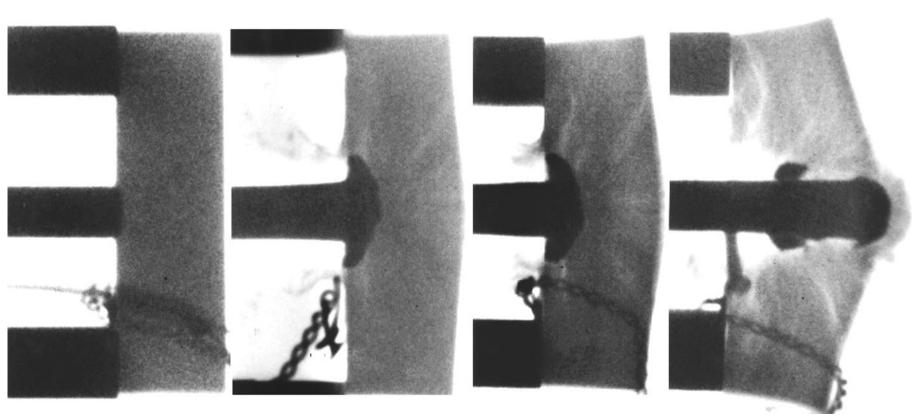

Fig. 16 An X-ray sequence showing a steel rod 10 mm in diameter hitting a block of soda-lime glass at a velocity of about 540 m s^{-1} [130]

and, although his own research interests did not initially include explosives, he inherited that work as part of the PCS Fracture Group after Bowden's death in 1968.

The science of explosives has always been something of a niche subject area, dominated by two quite distinct and different uses; mining and military. It splits further into safety studies (how to stop explosives from exploding) and performance studies (how to optimize the results when they do). Partly constrained by operational limitations on the kind of experiments that could reasonably be performed at the University, and partly due to the historical expertise in PCS that focused on safety issues, John built extensively on Bowden's contacts and funding from industry, the UK Ministry of Defence and the US Department of Defense to develop the Cambridge group into the foremost non-shock research group in the UK, and one of the most successful worldwide. While his primary interests remained in the areas of brittle fracture, liquid impact and friction, he nurtured the steady continuation of ground-breaking experimental research into explosive behaviour, additionally attracting sabbatical visits from distinguished scientists such as Phil Howe (Ballistic Research Laboratory at Aberdeen Proving Ground) and Jim Johnson (Los Alamos National Laboratory).

Initiation and propagation of reaction in primary explosives, exemplified by the creative work of Munawar Chaudhri on single crystals [136] and pressed beds [137], explored the unique sensitivity of these materials and included several efforts to find replacements for the ubiquitous, but still problematic, lead azide [138].

The initiation of both solid and liquid explosives by impact was explored extensively by several of his students and group members, including Heavens, Swallowe, Walley, Palmer and Bourne [124, 139–141], using innovative techniques such as the transparent-anvil drop weight, which allowed the viscous and visco-plastic processes that dominate high-strain-rate thermal localization mechanisms to be directly observed.

Dear [102] and Bourne [142] performed novel experiments to observe the initiation of transparent explosive gels by observing the detailed mechanism of the shock collapse of voids in the explosive, work that was later extended to the shock collapse of hollow propellant grains.

Significant advances were also made by Huntley, Palmer, Goldrein, Rae and others [113, 143] in understanding the mechanical response of polymer-bonded explosives (PBX) at lower strain rates using optical methods to track the 2-D strain field up to fracture.

Dickson and Luebcke [144] used transparent confinement to examine the progression of the deflagration-to-detonation transition in porous beds of the secondary explosive PETN.

Laser initiation of explosives became a significant new area of study in the 1990s. Ramaswamy studied the ignition of explosives by direct irradiation [145], while Dickson, followed by Watson, Goveas, Gifford and Greenaway [146, 147] investigated the direct shock initiation of secondary explosive by thin laser-driven metal fliers.

John was a regular attendee of the quadrennial International Detonation Symposium and the biennial American Physical Society Topical Group conference on Shock Compression of Condensed Matter, and he encouraged his students to attend them too, which helped to foster many international collaborations. His tireless commitment to pushing the existing boundaries of our understanding of explosives leaves an impressive legacy of advances in the subject.

George T. "Rusty" Gray III, Los Alamos National Laboratory, Cavendish Laboratory Visitor 1998

Rusty's interactions with Professor John Field, while relatively brief overall, had a lasting impact of great significance on both Rusty's scientific career as well as on the education and cultural acumen of his family. In the Fall of 1997 Professors Michael F. Ashby and J. David Embury, who both visited Los Alamos National Laboratory (LANL) regularly and were mentors of Rusty's, suggested that he might enjoy an extended research extended travel "sabbatical" within the University of Cambridge. Mike and David thereafter sponsored Rusty's application to become a visiting Fellow of Clare Hall within Cambridge University. Simultaneously, through a budding friendship with Neil K. Bourne with whom Rusty had interacted at APS Topical Conferences, he inquired about the possibility of spending 6 months at Cambridge University working within Professor Field's research group. Professor Field welcomed Rusty's interest in working with the PCS group, and he further helped secure funding from the Ministry of Defence to partially sponsor Rusty's visit and research within the Cavendish Laboratory, in exchange for agreeing to present a series of extended lectures on high-strain-rate and shock-loading behaviour in materials. So it was that Rusty arrived in Cambridge in April of 1998 for a 6-month visit as both a Visiting Fellow at Clare Hall and a visiting scholar within Professor Field's PCS research group. John and his staff further helped Rusty secure an amazing old house to rent off of Jesus Green in the centre of Cambridge. Rusty's family, including his 12 year-old son and 10 year-old daughter and wife would later join him for ~ 3.5 months of his stay.

The impact of this period on both Rusty's scientific research career as well as his family's life stories has been nothing but amazing. Rusty's research career, in so far as shock research, multiplied across many areas due to his interactions with John directly and through the breadth of research he conducted with staff within PCS including Drs. Bourne, Walley, Millett, and Proud [148–150]. New research topics in Rusty's career including shock-wave profile effects on shock hardening and spall, shear-wave loading effects on materials, and shear effects on damage, to name but a few, were all spawned during his time in PCS. His interests in shear-wave and friction effects on material damage were also the direct result of discussions with John, and papers John gave him to read, on the research of John's own Ph.D. advisor Professor Philip Bowden [9] as well as the work of Professor David Tabor [18]. John also encouraged Rusty, upon his learning of Rusty's interest in stained glass, to visit all the colleges in Cambridge to see the wealth of amazing stained glass in the various college chapels. Also, during this time, Rusty became acquainted with all of John's students and eventually one of them, Dr. Philip Rae, would come to do a Post-Doctoral fellowship with Rusty at LANL, and later join LANL as a staff member [151–154].

On a personal note, Rusty shares that he and his family were each enriched on so many levels during their stay at Cambridge. Rusty will never forget attending High-Table by candlelight with John and Neil within Magdalene College nor will his family forget their times punting on the Cam, touring Cambridge and Oxford, seeing Shakespeare plays performed in the evenings in Cambridge, or strolling on Jesus Green. Rusty shall always be indebted to Professor John Field for his friendship and the effect John has had on his career and his family.

Stephen G. Goveas, Senior Sponsor—Explosives, Trials & Test Estate Strategy, Atomic Weapons Establishment, Ph.D. awarded 1998—The Laser Ignition of Energetic Materials [155]

In 1987, Stephen arrived in Cambridge from Newcastle in the North of England. It was his first week as an undergraduate and John Field was one of the first fellows of Magdalene College that he met.

Stephen visited John in his rooms in the Lutyens Building and John welcomed him to the university and college. John was to be his Director of Studies and Stephen was excited at the prospect of studying Natural Sciences and the opportunities that John described. He thought John was an amiable, clever chap, but probably just another passing face in Stephen's career. He did not see that this was the start of a relationship that would stretch over 30+ years and that John would be an integral part of his life and career throughout those decades.

Over the next 3 years, Stephen and John regularly met to discuss studies, progress and, later, career options. Friendly chats in John's rooms and occasionally the Cavendish canteen, over a cup of tea and a slice of cake. Stephen gradually moved away from Physics and Materials to finally specialise in Theoretical and Physical Chemistry. Nevertheless, he stayed in touch with John, who was always keen to encourage young scientists to stay in science when they graduated (even if they had given up on Physics!).

In 1990, Stephen waived goodbye to Cambridge and started work as a scientist at the Atomic Weapons Establishment (AWE), a department of the UK Ministry of Defence (MoD). He was rather taken aback by the opportunity of leading experiments on the ignition and initiation of explosives using large and small lasers (surely, every boy's dream—certainly any boy excited by fireworks and the like).

Within a few months, he was asked to present his work to a senior MoD committee, and there was John, reviewing and advising on the technical aspects of his work and supporting his funding. Soon after this, Stephen restarted his studies with John as his supervisor, as he embarked on a Ph.D. and finally made the switch back to Physics, which pleased John greatly. John advised that he narrow his graduate studies to laser ignition for the purposes of his thesis and his time was shared between AWE and Cambridge. Stephen was going back to Cambridge and back to Magdalene College.

As with many of his other students, John delegated the day-to-day supervision of Stephen's studies to one of his trusted team, Neil Bourne, Director of Research—Stephen's first year undergraduate physics supervisor. It's a small world! Nevertheless, those occasion chats, gems of wisdom and advice, and an introduction to the politics of academia and government, resumed over cups of tea and slices of cake in the Cavendish and John's rooms in college, intermingled with notes of John's running career and reminisces.

Strangely, after a few more months, Stephen was asked to help place and manage an AWE research contract with Cambridge and a certain John Field, and Stephen was introduced to Peter Dickson, the postdoc who would carry out research supporting the other half of his AWE role, the laser initiation of explosives. Stephen had been introduced to Peter some years earlier, during his first year in Cambridge, by Neil. It really is a small world.

Over the following decades, John's and Stephen's path would cross many times. John sitting on many increasingly senior research and defence committees, reviewing and advising on the state of UK research capabilities and programmes; sometimes reviewing, providing direction and deciding on funding for the defence work that Stephen was involved in. Occasionally, Stephen would be presenting progress and proposals—a flashback to those research presentations to John and his Group in the Cavendish, many years before (and John still always had at least one question to ask!).

John was singularly respected within the academic research and defence communities, and his strengths included advising on and defending promising work, pulling strings to make sure things happened, filtering out blind alleys and wrong turns, and ensuring his research group was always well funded.

John was a strong character and not always the good guy. Stephen was aware of stories of the wrath of John, but he never experienced this himself. Sometimes they had rather heated debates and disagreements, and John would redirect or block Stephen's proposals, but he was always constructive in his criticism, he always provided a way forward and everything was fine after a cup of tea and a slice of cake.

Philip J. Rae, Scientist, Los Alamos National Laboratory, Ph.D. Awarded 2000—Quasistatic Studies of the Deformation, Strength and Failure of Polymer-Bonded Explosives [156]

Philip Rae interviewed for a Ph.D. student position in Prof. John Field's group as a result of a chance remark to Prof. Bradley Dodd—who studied adiabatic shear banding—who was working at the time at Reading University where Philip obtained his B.Eng. Philip asked Bradley if he knew anybody who studied the physics of explosives and might be looking for a Ph.D. student. In any event, Philip started his Ph.D. some months later at the Cavendish investigating the strength properties of polymer bonded explosives as part of a sponsored project for the Atomic Weapons Establishment (AWE). Although John was Philip's official supervisor, day-to-day mentorship fell to Dr. Tim Goldrein who himself had been a student of John and Dr. Jon Huntley.

Philip learned many valuable lessons from John over the years about the business of doing good science. John was not computer savvy (in fact for several years he had his secretary print all of his incoming email and he would handwrite a response on the bottom, sign it, and return it to her for typing); however, he did greatly value the assistance that computers and technology in general brought. John was a strong proponent of the idea that a good, clear, picture was worth a thousand words (or even equations). As a result, he kept a large collection of carefully produced 35 mm slides for all his talks. It was also the reason why the group focused so much on high-speed photography as well as employed a full-time professional photographer. At the time the Cavendish had only two professional photographers: one for John's group, and one for everybody else. John understood that a picture often explained a complex physical phenomenon better to scientists than words, but this was even more true of the layman (or project sponsor, often the same thing!).

As soon as laptop computers and portable projectors became viable, John quickly and willingly moved from slides to Power Point. This did mandate a designated Post-Doc (Tim Goldrein during Philip's time) acting as technical consultant and accompanying John to every presentation to set things up and fix inevitable Microsoft-based emergencies.

John was very good at estimating what a project would actually cost to execute. This was a valuable skill when, significantly before it became the norm in British academia, much of the group was continuously funded by industry, the Ministry of Defence and AWE. He also maintained a genuine open-door policy at his office. That is, the door would normally be open, and he was actually in the room. Although always available for advice, or to answer a request for funding a new widget, a conversation or even meeting would end with "*GooooD*". At which point either he would stride out of the room, or it was very clear that you would leave now. Philip also recalls that John would often end a question with "*…, Yes?*".

John had very few rules about hours and attendance, etc. There were just three. You were expected to attend the Thursday afternoon colloquia. Your research was high quality and on time (how that happened was up to you so long as it happened). And finally, your reports and presentations to the sponsors were professional. This also meant that everybody in the group had to become somewhat proficient at presenting and also good at a little 'marketing, expectation management and spinning' of your research (which was good training for real life).

It must be mentioned that at the time when Philip was at Cambridge, opportunities for academic advancement in the physics department were few to none. It is an unfortunate truth that by then the Physics department hierarchy viewed John's group as something of a group of blacksmiths and not real physicists. Since there was even less space at the Engineering or Materials Science department than at the Cavendish, a move there was out of the question from a practical point of view, even if the historical inertia was overcome. However, as an alternative John always encouraged students to make contacts both inside and outside UK academia as well as in industry. For example, it was expected, not just permitted, that students would attend one international conference a year as well as at least one UK-based one. The only cost saving measure was that you were expected to share a hotel room with another student or recently converted Post-Doc on such ventures.

Because much of the science that John championed was aimed at a real end user, not just of academic interest, John also made sure that experimental apparatus and consumables could actually be made and repaired. In that regard he followed the old Cavendish rule that there should be numerous skilled craftsmen readily available who could make the impossible based on a badly drawn sketch on a napkin. Philip thinks while everyone in the group was aware that there was such a thing as technical drawings, the group did not really think they applied to them. A few minutes' conversation and some hand waving usually got things built to specification.

Philip shares, "*I think I would have been happy as a researcher at the Cavendish, but as a result of connections made at some of the international conferences John encouraged me to attend, I joined Los Alamos National Laboratory in the US about 18 months after I obtained my Ph.D*." Philip did have the opportunity ten years ago to undertake a six-week sabbatical at the Cavendish PCS group. John had long retired by then, but the group at that time retained much of the same character, John's influence was still felt and it was a highly enjoyable experience.

Marc Meyers, Distinguished Professor of Materials Science and Engineering, Departments of Mechanical and Aerospace Engineering and Nanoengineering, University of California, San Diego Cavendish Laboratory visitor

In the mid-eighties, Marc Meyers laboured in New Mexico, USA and conducted explosive experiments in the mountains around Socorro. One day, he and his colleagues had a strange idea, to create a Center for Explosives Technology Research in the middle of the desert! They got state funding and were fortunate to attract a brilliant researcher as director in Per-Anders Persson [157] who left Nitro Nobel to join them. Soon they received the visit of two of his Cambridge friends: John Field and Munawar Chaudhri. Per Anders and John had been students at the Cavendish lab and were both athletes: one a high jumper and the other a runner. This enhanced Marc's admiration for them. From the first moment, Marc was amazed at John's knowledge of explosives and at his fundamental insight into the processes of explosive initiation. In deep awe of the group at Cavendish, where pioneering work by Frank P. Bowden [9], David Tabor [18], Abe D. Yoffe, and John E. Field had been conducted, Marc managed to visit the Cavendish on several occasions and conduct research there. John was always the most gracious host and invariably invited Marc for lunch and dinner. Marc had the opportunity to gauge the positive effect John had on the entire PCS group and the admiration that John elicited even after his retirement. John was nominated for the DYMAT 2009 John Rinehart Award, which he received, and gave a brilliant lecture on that occasion, in Brussels, Belgium at the Belgian Royal Military Academy (this lecture was not part of the conference proceedings, but the content that lecture may be found in [77]).

In the mid 2000s, Marc Meyers spent a sabbatical at the PCS Group. He returned a few times and always had the opportunity to conduct meaningful research. He used the drop-weight test apparatus to generate high compressive stresses and strains in reactive mixtures of PTFE-Al-W. These tests were combined with high-speed photography to determine the plastic deformation of the mixtures under confinements produced by machined aluminium disks of varying thicknesses. The high-speed photography was accomplished in the historic C 4 camera, and Steve Walley showed an amazing mastery of extracting excellent data form fifty-year equipment. It had been used earlier for recording nuclear explosions and was an impressive machine. Shear localization of the mixtures was identified and a peculiar behaviour of the PTFE was registered: A network of these PTFE nanofibers is also shown in Fig. 17 [158]. They are evidence of crazing which had been observed by Brown et al. [159] earlier, but with the fibres having a much larger diameter.

This work on the dynamic behaviour of reactive mixtures, funded by the US Office of Naval Research Award, led to research funded by the European Research Office, in which explosives were used to establish the fragmentation of aluminium and nickel-aluminium compacts. These compacts were made by a swaging process in which the particle size and interface cohesion were independently varied. Chris Braithwaite, then a post-doctoral fellow at Cavendish, did most of the experimental work using an explosive chamber coupled with a high-speed camera. The apparatus is shown in Fig. 18 and consisted of an explosive chamber activated by an explosive cap placed in the axis of a copper hollow cylinder around which the ring was placed. The detonation drives the expansion of the copper tube which, in turn, accelerates the ring. The camera recorded the velocity of expansion as well as the fragmentation process. The mean fragment size and fragment size distribution were measured from the specimens embedded paraffin from which they were recovered by melting the latter. This was an exhausting process since the fragments had to be separated from the liquid and then individually weighed in order to obtain

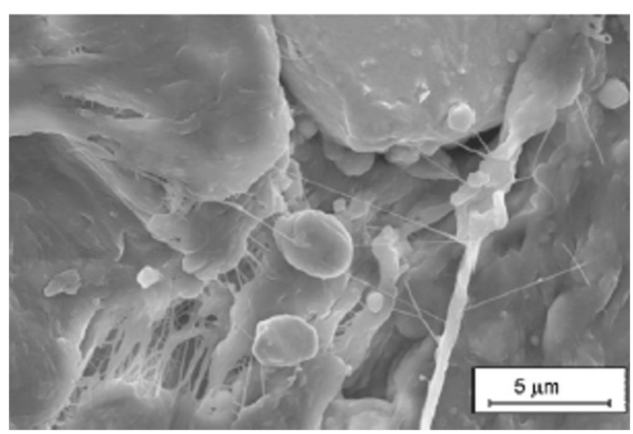

Fig. 17 PTFE nanofibrils generated by high velocity compressive deformation under confinement of Al-PTFE-W compacted mixture. From [158]

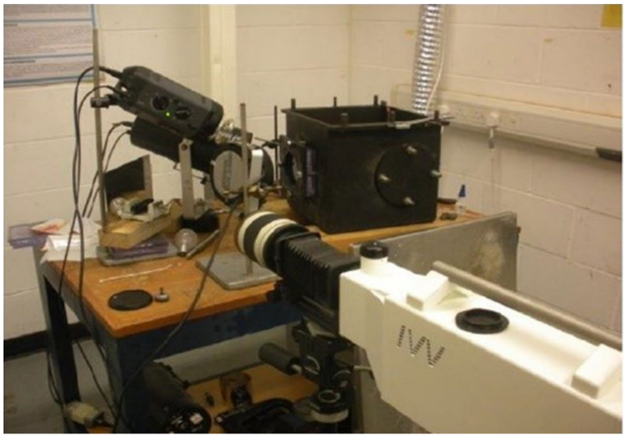

Fig. 18 Expanding ring setup driven by detonation of explosive cap and associated diagnostics. From [164]

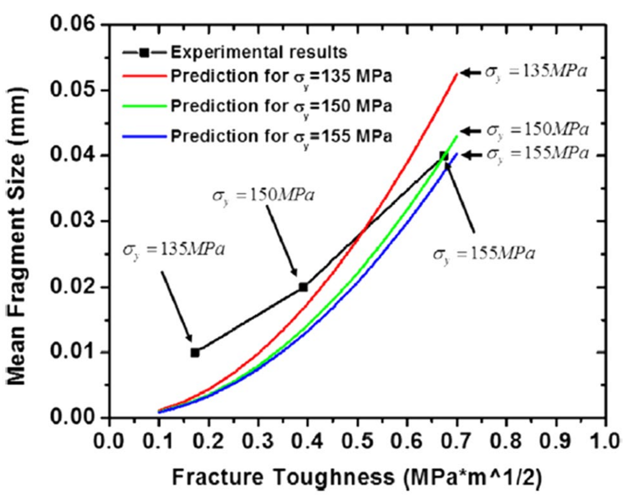

Fig. 19 Fragment size in Ni–Al compacts as a function of fracture toughness and yield strength; full lines are theory predictions using a modified Mott theory and squares are experimentally-determined values. From [165]

a meaningful distribution. The fragmentation statistical distribution was compared to was compared to the famous Mott model [160–163]. In Mott's days fracture mechanics was still in its infancy. Our contribution was to incorporate fracture mechanics into Mott's energy balance equation. The mean fragment size was found to be dependent on both yield strength and fracture toughness of the compacts, which were separately determined. The results of experiments and calculations are shown in Fig. 19 for Ni–Al compacts. One can see a very satisfactory correlation between the two.

During his visits to Cambridge, Marc fondly remembers the fantastic library in the PCS group. In spite of the availability of internet, the physical library was essential in his pursuits, since an enormous amount of knowledge was accumulated in one room. He also remembers the coffee and tea breaks which provided the opportunity for the group members to exchange ideas and information. The sorties to the local pubs added the needed lubrication to these creative minds. Marc became a Life Member of Clare Hall and had the opportunity to enrich his intellectual life.

Clive R. Siviour, Professor in Engineering Science, University of Oxford, Ph.D. Awarded 2005—High Strain Rate Properties of Materials Using Hopkinson Bar Techniques [166]

Like many of John's students, Clive Siviour started as a Part III (final year) project student in John's Fracture Group, and stayed for a Ph.D., finishing in 2005. Clive's research focussed on using the split-Hopkinson pressure bar to evaluate the response of quite a variety of different materials. This led to a series of influential papers on temperature—strain-rate equivalence in polymers [77, 167–170]. However, research he later did at Luleå, as part of John's collaboration and trips to the university, mainly focussed on 3D image correlation (often called Digital Volume Correlation) on X-ray Tomography scans of powders under compression.

John's leadership of the Fracture Group very much encouraged good (publishable!) science, but with an eye on providing data that helped to understand problems of industrial importance. One of the features of the group was that there were a number of very good post-docs and students working on a wide variety of topics: shock loading, explosive detonation, mechanical response at low and high strain rates, bubbles, various optical techniques, diamond, and liquid and solid erosion. This meant that students were quickly exposed to different techniques and ideas, with plenty to talk about at the well-observed morning and afternoon tea breaks. This provided fertile ground for new ideas to develop, such as the work combining the split-Hopkinson bar and Digital Image Correlation (Fig. 20). Another advantage of working with John was the huge number of friendships and contacts he had, which allowed a young student to interact with some of the leading researchers in the field, and also to develop their own contacts for the future, both of which Clive found very helpful as he developed his career. John was quite quiet, but he was excellent at engaging with people, and always had the right question to ask about their family, or some other aspect of their personal lives.

Throughout Clive's time in Oxford, John's support was invaluable, not just for references but also to encourage focus on the right activities. The split-Hopkinson bar and high-speed photography continue to be two key components of his research, which still focusses on the experimental study of mechanical behaviour of materials, and development of

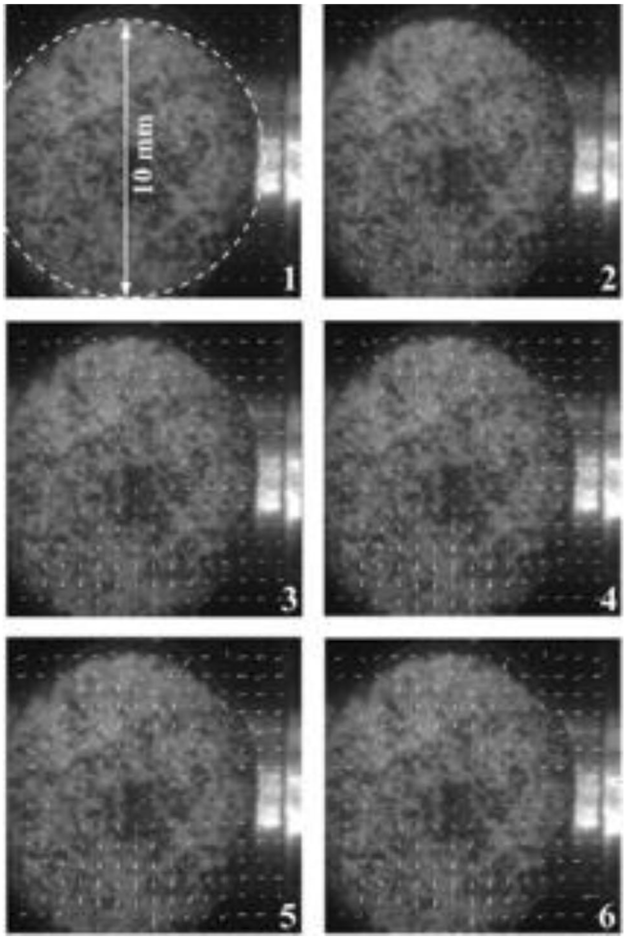

Fig. 20 Application of Digital Image Correlation to a high-speed Brazilian test on a PBX simulant [171]

techniques for measuring these properties, continuing, to some extent, the Fracture Group philosophy of designing new experimental techniques to help solve relevant industrial problems.

David M. Williamson, Principal Research Associate at the Cavendish Laboratory, University of Cambridge, Ph.D. Awarded 2006—Deformation and Fracture of a Polymer Bonded Explosive and Its Simulants [172]

David Williamson first came to Cambridge almost immediately after finishing his physics degree course at Loughborough; in his recollection arriving before he had even graduated. From 8 July to 30 September, 2002, he was employed as a Technical Vacation Assistant to Professor John E. Field; a prelude to beginning his Ph.D. studies under John that October of 2002. David came on the recommendation of another of John's former Ph.D. students, Gerry Swallowe (Ph.D. 1975–1979 [63]), who strongly recommended John to David as a supervisor. David shares that it is no exaggeration to say that John played a very influential role in his life; in signing David up to Magdalene College, John set the scene for David meeting his future wife Nataliya.

John excelled in dovetailing academia, industry and government, and to David's mind, it is in that role that he thinks he learnt the most from John. David recalls that one of his first, of what have become many outings from the Laboratory, was to attend a TEEMAC meeting; and David remembers feeling very proud that it was his supervisor who chaired the proceedings with such ease. As well as being academically rigorous, John was also a highly entrepreneurial individual. As director of his own limited company, John engaged David in numerous projects over a ten-year period. John gave David the example of how it was possible, within the Cambridge environment, to not only to develop academic skills, but also to put them to use in the wider world.

David travelled a little with John, and a particularly memorable trip was to Singapore in 2012 to deliver a series of lectures at Nanyang Technical University. Whilst there, they were very well looked after by another of John's former students, Qiqing Sun (Ph.D. 1987–1992 [173]), and the mutual respect and friendship was obvious and natural. It was on that trip David saw John at his most relaxed, and they talked the most freely. John was very familiar with the layout of the city, and seemed to have an innate knowledge of the bus routes and timetables. On a shopping trip to buy silks and thousand-layer cake for his wife Ineke, David thinks John was the happiest he ever saw him. They took tiffin at Raffles Hotel; a memory that David will always remember and hold dear.

From the early 1960s to the late 2000s, John supervised around 84 students (shown in "Appendix"); that is approximately one for each year of his life. Their collected theses are kept in the Cavendish Laboratory, and continue to be an invaluable resource for David's own Ph.D. students; such is the enduring nature of John's research interests. As David supervises them today, he incorporates the lessons he learnt from John over the 18 years that he was privileged to know him.

David was amongst one of the last cohorts of John students, it is no surprise therefore that David regularly meets former students at conferences and meetings both in the UK and around the world; and all remember John fondly. Surely those individuals and their on-going research are both testament to John's success, and his greatest legacy.

Conclusion

Professor John E. Field was widely regarded as a father figure in high-strain rate physics who inspired many during his lifetime. John made major contributions to our understanding of friction and erosion, brittle fracture, explosives, impact and high strain-rate effects in solids, and impact physics during his career in the Physics and Chemistry of Solids (PCS) Group of the Cavendish Laboratory at Cambridge University. The contributions by the PCS group are globally recognized and the impact of John's work is a lasting addition to our knowledge of the dynamic effects in materials. The legacy of his work and his students have made an indelible mark on the field.

Appendix

Ph.D. Students Supervised by Professor J. E. Field with Year and Title Dissertation was Published

1967	Anthony D. Heyes	Velocity of brittle fracture and the interruption of electric currents
1968	Javia Soria-Ruiz	Decomposition of solids by brittle fracture
1969	Munawar M. Chaudhri	The initiation of fast decomposition of explosive crystals
1970	Howard S. Dobbs	Brittle fracture and its application to circuit breaking
1970	Melvyn J. Twigg	The propagation of brittle fracture
1971	Graham D. Coley	Initiation and growth of explosion in liquids
1971	Ron E. Winter	Microdeformation of materials by impact and slow loading
1972	Mohammed A. Zafar	Laser damage in transparent dielectrics
1973	Stephen N. Heavens	The initiation of explosion by impact
1973	Keith F. G. Fuller	The brittle fracture of polymers
1973	Joe T. Hagan	Some aspects of brittle fracture and laser damage in dielectrics
1974	Alan C. Woodward	Crack propagation in glasses
1974	David A. Gorham	High velocity liquid jets and their impact on composite materials
1974	Clifford J. Studman	Impact damage to brittle materials during the tillage of stony soils
1974	Ian M. Hutchings [2]	The erosion of ductile metals
1975	Michael Coley	Initiation and growth of explosion in liquids
1977	David G. Rickerby	High speed liquid impact
1977	Hermann M. Hauser [25]	Mechanically activated chemical reactions
1978	M. John Matthewson [32]	Protective coatings and mechanical properties of materials
1979	Gerry M. Swallowe	Effect of grit on the impact initiation of explosives
1980	David R. Andrews [43]	Erosion of Metals
1981	Sybrand van der Zwaag [44]	Strength and impact properties of IR transparent materials
1991	Paul W. Blair	The liquid impact behaviour of some composites and infra-red transparent materials
1982	Alvin W. Wilby	Studies of aerodynamics drag
1982	Stephen M. Walley [47]	Erosion of polyethylene by solid particle impacts
1984	Chris J. Freeman [93]	Strength and fracture properties of diamond
1984	Peter H. Pope	Dynamic compression of metals and explosives
1984	John P. Dear [98]	The fluid mechanics of high-speed liquid/solid impact
1985	Chris D. Hutchinson	The response of intermediate explosives to thermal and shock stimuli
1985	Murray A. Parry	High-speed photography of ignition and propagation of fast reaction in some explosives
1985	David Townsend [107]	Liquid impact properties of brittle materials
1987	Jonathan M. Huntley [111]	Laser speckle and its application to strength measurement and crack propagation
1987	Irene M. Scullion	Erosion by solid particle impact
1987	Ian P. Hayward	The frictional and strength properties of diamond

1987	Simon N. Mentha	High strain rate deformation of metals
1987	Floris M. P. Heukensfeldt-Jansen	Investigations of the solid particle erosion properties of polymers
1987	Russell J. Hand	Impact and Fracture Properties of Infra-red and Optical Trans-mitting Materials
1988	Timothy G. Leighton [118]	Response of gas-filled cavities to acoustic field
1988	Peter N. H. Davies	Multiple impact jet apparatus
1988	Nicolas A. Safford	High strain rate studies with the direct impact Hopkinson bar
1990	Neil K. Bourne [123]	Shock wave interactions with cavities
1990	Peter M. Dickson [131]	Fast reaction in primary explosives
1991	Zhu P	The strength and friction properties of diamond
1992	C. S. James Pickles	Infra-red transmitting materials in a high velocity environment
1992	Qiqing Q. Sun	Solid particle erosion and ballistic impact
1992	Colin E. Seward	Multiple impact jet apparatus (MIJA) and its application to liquid impact erosion studies
1992	Martin B. Whitworth	Studies of dynamic fracture using speckle techniques (with Dr J M Huntley)
1993	Emma D. Nicholson	Measurement of the mechanical properties of high modulus coatings
1993	A. Lalitha Ramaswamy	Laser initiation of explosives
1993	Pauline P. J. Holes	Strength deformation and explosive properties of polymer bonded explosives (PBXs)
1994	Chris W. Beton	Numerical analysis of the acoustic emission of bubbles
1994	Andrew J. Hardwick	Bubble sizing using acoustic methods (with Dr A J Walton)
1995	Peter L. Kaye	Erosive cleaning of surfaces
1995	Peter E. Luebcke	Deflagration to detonation transition
1996	Frank M. van Bouwelen	Characterisation of CVD diamond
1996	Stefano E. Grillo	The Friction and Polishing of Diamond
1996	H. Timothy Goldrein	Applications of Optical Strain-Measurement Techniques to Composite Materials
1997	Edward J. Coad	The Response of CVD Diamond and Other Brittle Materials to Multiple Liquid Impacts
1997	Gail H. Jilbert	Solid particle erosion of infrared transmitting materials, including coated samples
1997	Natalie H. Murray	The response of alumina ceramics to plate impact loading
1998	Simon D. Galbraith	Plate impact studies of energetic materials
1998	Steve G. Goveas [155]	The laser ignition of energetic materials
1998	Claire F. Kennedy	Liquid impact of IR materials: equipment development, damage thresholds and transmission losses
1998	Stuart Watson	The production and study of laser-driven flyer plates
1999	Alistair G. Thomas	The mechanics of coating removal in jet and pipeline flow
1999	Robert H. Telling	The fracture and strength of natural and synthetic diamond
2000	Philip J. Rae [156]	Quasistatic studies of the deformation, strength and failure of polymer-bonded explosives
2000	Lucy C. Forde	Ballistic impact of rods
2001	Jens E. Balzer	Low-level impact loading of explosives
2001	Martin W. Greenaway	The development and characterization of a laser-driven flyer system
2001	Michael J. Gifford	The role of hot spots in the ignition and growth of explosion

2002	Alun R. Davies	Solid particle erosion of freestanding CVD diamond
2002	Jonathan R. Hird	The polishing of diamond
2002	Steve G. Grantham	Digital speckle radiography
2004	Geoff R. Willmott	Shock studies of kimberlite, diamond and brittle embedded particles
2004	Ruth I. Hammond	Shock and ballistic properties of bainitic steel and tungsten alloys
2004	Avik Chakravarty	Electro-optic studies of low-level luminescent processes
2005	Tacye Phillipson	Temporal and spatial studies of embedded triboluminescent crystals
2005	Clive R. Siviour [166]	High strain rate properties of materials using Hopkinson bar techniques
2006	David M. Williamson [172]	Deformation and fracture of a polymer bonded explosive and its simulants
2006	Helen J. Prentice	Development of stereoscopic speckle photography techniques for studies of dynamic plate deformation
2007	Helen Czerski	Ignition of HMX and RDX
2007	Edward Zaayman	The fracture of diamond
2008	Adam Parker	Characterisation of novel high explosives for initiator and explosive train applications

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