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IRPS Bulletin

Newsletter of the International Radiation Physics Society

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The 200 ton, 10m diameter vacuum vessel contains a high precision electron energy spectrometer. By applying a retarding potential to the electrons emitted in the beta-ray decay of tritium it is possible to determine the mass of the neutrino emitted in the decay process very precisely.
Photo: Kahlsruhe Institite of Technology

At Mooloolaba, Queensland, Australia *(photo S McKeown)*

CURRENT IRPS COUNCIL MEMBERS 2021-2024

Contents of this Journal

From the Editor

This is the **first** Issue of the IRPS Bulletin in 2022. And it contains a number of **firsts**.

Isabel Lopes is the IRPS's **first** Female President: her **first** President's Column is to be found in this issue.

Reports of the ISRP-15 Meeting and the IFARP-3 Meeting, both held in Kuala Lumpur, Malaysia have been prepared by Mayeen Khandaker and David Bradley.

Information concerning future conferences conducted under the IRPS auspices will be presented later in this issue.

Dudley Creagh has provided items for the *Physics from around the World* section. Dudley is hopeful that there are scientists out there who read about important advances in science and who are willing to communicate these advances with others in our society. The reportage is intended to be informal and informative: **not** a magnum opus. One of the principal aims of our society is the cross-communication of information between disciplines/research fields.

This is the **first** Edition of the Bulletin which I will have produced since Council ratified my appointment earlier this year. Shirley McKeown has provided me with assistance in its production, and I, and my predecessors, are grateful to her for her enthusiastic support for the past 30 years.

Ming Tsuey Chew

From the President

Dear Colleagues

I am very pleased to write this first letter as incoming president of the International Radiation Physics Society (IRPS), a society with a proud past and an exciting future.

I would like to start by thanking IRPS members for placing their confidence and trust in me to serve as President of the Society. It is a genuine honour to take up the position as incoming President and I hope to meet your expectations.

I feel privileged and eager to take after a list of distinguished scientists who served as Presidents of IRPS before me. They have carried out their mission with unlimited dedication and wisdom. In particular, I would like to underline Prof. David Bradley's excellent work as President in the last 3 years, a time that, for obvious reasons, presented considerable challenges for the IRPS as well as our members.

According to the Constitution of IRPS, its primary objective is "to promote the global exchange and integration of scientific information pertaining to the interdisciplinary subject of radiation physics". The IRPS Constitution defines "radiation physics" as "the branch of science which deals with the physical aspects of the interactions of radiations with matter". It is then intrinsically linked to the broad spectrum of radiation applications, which are extremely diversified and interdisciplinary. For instance, it is doubtless that the exciting field of particle and astroparticle physics relies on ingenious and complex detectors that, in turn, are based on advanced and highly precise knowledge on the interaction of radiation with matter and detector technology. It is the case of the complex detectors of LHC's experiments at CERN, such as ATLAS and CMS, which discovered the Higgs boson. The same can be said about the ingenious detectors and methods developed for dark matter direct detection. To disentangle the extremely rare events we are looking for from the much more abundant background, one must know with high precision the details of the interaction of all the particles with the detector medium.

The particle and astroparticle physics are just an example among the numerous areas that have strong links to radiation physics. The field of radiation physics has much to contribute to society in different areas, as for instance biomedical applications, energy choices in their pursuit of non-carbon based energy sources, environmental sciences, security applications, study of materials and culture heritage.

To promote the global exchange and integration of scientific knowledge on radiation physics in its various dimensions, IRPS co-organizes and sponsors three series of triennial conferences:

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* the "International Symposium on Radiation Physics" (ISRP) series that encompasses the current trends in the broad area of radiation physics and whose first edition was in Calcutta in 1974,

* the "International Topical Meeting on Industrial Radiation" (IRRMA) series, which aims bringing together scientists and engineers interested in radiation and radioisotopes measurements and

* the "International Conference on Dosimetry Applications" (ICDA) series dedicated to current trends and potential future issues in ionising radiation dosimetry.

The IRPS members have a reduced fee in all these conferences.

Despite the limitations imposed by the covid-19 pandemic and thanks to the hard work and dedication of Prof. David Bradley and the Organizing Committee, the ISRP-15 took place in December 6-10, 2021, in Kuala Lumpur, Malaysia, in a hybrid model, i.e., with online and onsite participants. It went extremely well and was a credit to all organizers and attendees, as well as to the Society.

Also with the objective of promoting the exchange of scientific knowledge on radiation physics, the society publishes a periodical bulletin. It includes topical and review articles, membership pages and notices of upcoming conferences and calendar items related with Radiation Physics. The bulletin is a vehicle for the exchange of ideas and information among scientists dealing with various aspects of radiation physics worldwide. As more people engage in its production and publication, the more vibrant it will be. Thus, let me invite you all to contribute by putting forward material to be considered for publication. It can be a topical article on the research in which you are involved or a review article on an interesting topic in which you have worked or you are acquainted with, or a topical comment. You can also send just a piece of news on your institution or country, or advertise an event related with radiation physics.

The bulletin is sent electronically to all IRPS members and it is posted online on the IRPS website http://www.canberra.edu.au/irps

In my view, one of IRPS strengths comes from being an international forum of researchers engaged in a large variety of different topics, both fundamental and applied, under the broad umbrella of Radiation Physics. I find this diversity immensely valuable. Moreover IRPS is an inclusive society truly engaged in promoting international links, collaborations, and knowledge exchange, with

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particular attention to the inclusion of countries with economies in transition and developing economies.

Looking ahead, I am convinced that the Society has a role to play promoting research across the spectrum of Radiation Physics, all over the world, in particular the developing countries. There are definitely challenges ahead, but I am confident we can meet them.

I will seek to build on the work of my predecessors in welcoming and celebrating diversity, and in making IRPS truly inclusive in all senses. One of my prime concerns will be to reach out to researchers in geographic areas where doing science is more difficult. Another, will be to promote the Society's appeal to young researchers worldwide, giving them opportunity to present their research results in our conferences and bulletin.

For that, I look forward to the collaboration with the other members of the Council and all members of the Society. You are all needed, and I count on all of you.

A new President means a new directory board. I would like to thank the colleagues that accepted to be with me in this term, Christopher Chantler as Chair of the Advisory Board, Tomás Trojek as Secretary, Amir Bahadori as Treasurer, Eric Shirley as Membership Officer and all the Vice Presidents and members of the Executive Council.

I wish you all a successful year, hoping that the world will gradually open up and we'll be able to meet face-to-face again.

Isabel Lopes

Musings of the Immediate Past President

For the last two years of the IRPS 2018-2021 Presidency the drag that SARS-CoV2 was having upon the conduct of our Society affairs was becoming tangible. Face-to-face Council meetings had undoubtedly aided our detailed planning of previous IRPS events, the Society until that time holding one major international meeting per year. These events were nicely cycled on a triennial basis, intended to ensure that our events were both regular and avoided conflict with each other in attracting our membership to attend. Until 2018 all of our Society events had been 100% live and, prior to the advent of the virus SARS-CoV2, all had been held without interruption or delays. These meetings have aligned with our efforts to be a Society truly representing our international agenda; challenges apart, we continue to see new hosts for our meetings, this in-spite of the vagaries in planning that are presented by the viral outbreak. Hosts include those for our foundational International Symposia on Radiation Physics (ISRP) series, the International Topical Meetings on Industrial Radiation and Radioisotope Measurement Applications (IRRMA) series and the International Conference on Dosimetry and Applications (ICDA) series. We have been able to maintain the triennial cycle for the foundational series ISRP, with ISRP-15 held in Kuala Lumpur, 6-10 December 2021 (preceded by a Workshop focusing on radiobiology, 5th December), albeit with the great majority of talks presented virtually, something that we have now largely gotten used to. Conversely the Moscow IRRMA 2020 needed to be delayed until this 3- 8th July, becoming IRRMA2022 (http://www.lnf.infn.it/conference/irrma2021/) it also being anticipated that it will be be a 100% live attendance event. This has had a knock-on effect on ICDA4, now expected to be held in Valencia later this year.

We all of us sense, with digital communication coming to the rescue of the very many thousands of conferences around the world, that there are going to be big changes to the way in which future conferences are held, not least many stakeholders finding the virtual presence option to be useful (presenters, other attendees and institutional funders). From personal experience of organizing ISRP-15, the hybrid meeting is definitely a hard task to arrange; I will let the reader imagine the very many hurdles. interaction of face-to-face meetings and expect to feel impeded in confronting the Nothing is perfect and change is hard to accommodate; I for one enjoy the personal reality of future movement restrictions, nevertheless recognizing the need for a reduced carbon footprint. I expect, more than ever before, that my own future conference travel plans will be enormously rationalized against the many expected benefits.

Returning to the challenges of the period 2020 -2021, it was not at all clear how the Society might best carry out its functions, sharing in a global dilemma and the

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Past President's Report continued:

tremendous burden of loss and suffering that we have all witnessed. We nevertheless tried hard to maintain regular activities of the Society.

This included pushing ahead with the main communication channel of the Society, our vibrant Bulletin, now with a new Editor in post, Dr Ming Tsuey Chew (a radiobiologist). We also witnessed the holding of the second of two regional meetings hosted in Kuala Lumpur, the 3rd International Forum on Advances in Radiation Physics (IFARP-3), held at Sunway University at its campus located just outside of Kuala Lumpur (https://university.sunway.edu.my/sunway-in-the-news/3rd-international-forum-on-advances-in-radiation-physics), helping to engage ASEAN and Oceanic participation.

This meeting, conducted entirely online via Zoom on the 24th and 25th February 2021. IFARP-3 was hosted by Sunway University and the University of Melbourne, with Universiti Putra Malaysia as a collaborating body. This regional meeting was the third in a series born out of the efforts of Professor Jorge Fernandes, the first being hosted by the University of Bologna at its site in Buenos Aires, termed FORUMBA (Forum on Advances in Radiation Physics, Buenos Aires, 4-5 May 2017). This year will see IFARP4, to be held in Riyadh in late March, the first ever meeting sponsored by this Society to be held in the Middle East. Accordingly, the Society now looks forward to adding Russia and Saudi Arabia to the locations in which its meetings will have been held.

With a world in turmoil, we look to be upbeat; it appears for the first time since the onset of the viral outbreak that the WHO are reporting a downturn in case numbers. We can only hope that this signals a downward trend and with it a return to optimism, once again with us enjoying some of the freedoms we had previously taken for granted. Finally, on a personal note, my associations with this Society date from its very beginnings, starting with the formation of the Protem Committee in 1982, one that set up the Society. My advocacy of the Society remains passionate (apologies for using a word that so often seems so very overused, although not in this case). In this 37th year of its existence, I look forward to seeing this Society go from strength to strength and with it for more of my fellow scientists to join with us in taking this Society forward to the greater benefit of all.

David Bradley, *18th February 2022*

Addenda : *This summary was omitted in the last edition of the IRPS Bulletin*

Profile of Member

Tomas Trojek is the head of the Department of Dosimetry and Application of Ionizing Radiation at the Czech Technical University (CTU) in Prague. He graduated in Nuclear Engineering in 2001 and defended his PhD thesis five years later at the CTU.

A part of his PhD thesis was done at the ISIB in Brussels and the UPV in Valencia. In 2013 he became Associate Professor in Applied Physics.

His research activities have included Monte Carlo calculation of radiation transport in matter,radionuclides in environment, high energy physics, and X-ray fluorescence analysis and its applications.

He has worked in the Laboratory of X-ray spectrometry at the CTU since 2001, where he was initially engaged with X-ray fluorescence analysis of art and archaeological objects. His further activities in this field are related to in-situ analysis and elimination of disturbing effects in quantitative data evaluation. Also, he has been promoting the use of Monte Carlo simulation in quantitative XRF analysis. At present, he is engaged with confocal XRF and other depth-profiling XRF techniques.

Apart from the X-ray techniques, Tomas was also involved with monitoring of radionuclides in environment. It included in-situ gamma spectrometry and laboratory analyses of samples. Last but not least, he has taken part in the experiment DIRAC in the CERN laboratory in Switzerland since 2001. The main goal of this experiment is to measure the lifetime of atoms made of Pi and K mesons.

He is the author or co-author of more than 65 papers published in international journals and he was awarded the CTU Rector's Award for excellent scientific results in the year 2010.

Tomas has been a member of IRPS for more than 11 years and an Executive Councillor in the last 6-year period. He participated in organizing the conferences held in Prague, i.e. ISRP-8 (2000), IRRMA-7 (2008), and ICDA-1 (2013).

Report : ISRP 15, 2021

15th in the series of the popular and prestigious International Symposia on Radiation Physics (ISRP-15), this meeting otherwise referred to as ISRP 2021, was held on December 6 – 10, 2021 as a hybrid mode event (providing for both "physical" and "online" platforms). In deciding to operate the meeting as a hybrid event it was intended to facilitate the needs of as many people as possible, accommodating matters of convenience and confronting the limiting factors of the COVID-19 pandemic. The "physical" part of this symposium was held at Sunway University, bordering Kuala Lumpur, Malaysia. The meeting was organised by the Research Centre for Applied Physics and Radiation Technologies (CAPRT) at Sunway University and was conducted in collaboration with Universiti Teknologi Malaysia and Universiti Putra Malaysia, also being supported by pan-Malaysian universities and Research Institutes.

The well-known ISRP series are one of the regular activities of the International Radiation Physics Society (IRPS), founded as it was in Ferrara (Italy) in 1985.

This international symposium sought to bring together research leaders, distinguished experts and scholars from within the various scientific areas of Radiation Physics, attracting people from across the globe. In this, the wish was to share knowledge and experiences in current research, achievements taking in the very many diverse fields that come under the umbrella of 'Radiation Physics and Applications'. Indeed, with this symposium taking place during the covid outbreak, this event provided a considerable opportunity for the radiation physics community to introduce and interact with their peers, showcasing their newest research results, advances, innovative ideas and discoveries. The 15th ISRP was devoted to current trends and potential future issues involving the uses of radiation in many fields such as biomedical applications of radiation, art and cultural heritage, Monte Carlo methods and models, radiation in environmental sciences, detection of threat material and contraband, radiation protection, shielding and dosimetry, radiation effects on materials, radiation detection and measurements, and other related topics.

A total of 329 participants were attracted to the meeting, coming from more than 44 countries, including from Algeria, Australia, Argentina, Brazil, Bangladesh, China, Croatia, the Czech Republic, Denmark, Egypt, Finland, France, Germany, Indonesia, India, Italy, Iran, Japan, Jamaica, Jordan, Korea, Malaysia, Mexico, Nigeria, Norway, Pakistan, Portugal, Qatar, Romania, Russia, Saudi Arabia, Singapore, Spain, South Africa, Sudan, Taiwan, Thailand, Tanzania, Turkey, the United Arab Emirates, the USA, UK, Vietnam and others. The meeting sessions were contributed to by plenary speakers, keynote lectures, and invited lectures,

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also with leading experts presenting work in the form of oral and poster presentations, also welcoming contributed papers. A workshop on thematic issues in radiobiology preceded the main event.

The high number of representatives from across the globe once again clearly demonstrated the significance of radiation physics and its growing interest to the research community worldwide.

A Proceedings of ISRP 2021 (with submissions subject to peer review) will appear in the prestigious Elsevier journal 'Radiation Physics and Chemistry (RPC)'. This special issue will intend to reflect the very many interdisciplinary issues of radiation physics, including theoretical and experimental research in radiation physics, research into physical aspects of the interaction of radiation with inert or living material, education in radiation physics and the use of radiation for peaceful purposes.

This symposium could not have been organized without the strong support and help from the committee members of ISRP 2021. Sincere thanks go to Prof. D.A. Bradley (now Immediate Past president of IRPS) for his great help and support in organizing this symposium.

Mayeen Khandaker (Co-Chairperson of ISRP 2021)

Conference Reports

Upcoming Conferences

March 27-31, 2022 : IFARP-4 , King Saud University, Riyadh City, Saudi Arabia

for full information :

https://www.mefomp.com/The-4th-International-Forum-on-Advances-in-Radiation-Physics-IFARP_a7218.html

Conference Cancellation

Due to present circumstances it is with much regret that we must announce that the **IRRMA 2022 meeting** cannot proceed.

Arrangements for the next IRRMA meeting will follow in due course

Physics from around the World

The following section contains two items, one on neutrons and neutrinos, and the second on wave-particle duality. The first item gives a background to the discovery of neutrons and neutrinos and then connects four recent important discoveries/news items concerning neutrinos. The second describes a new experiment demonstrating wave-particle duality using neutron interferometry.

Items in this section are more journalistic than scientific in presentation: hopefully they present information in a more interesting fashion than a journal article. They are not meant to be the last word on the topic. For example: almost as I write, results have been published of an experiment to determine the mass of the electron anti-neutrino emitted in the β-decay process by tritium ($^3H_1 \rightarrow {}^3He_2 + e^- + {}^a\nu_e$). This was conducted at KATRIN (Kahlsruhe, Germany) and has shown that the mass of the neutrino is <0.8eV/c^2 (Nature Physics 1 February 2022).

Members are encouraged to submit copy to this section of the Bulletin. Indeed, if you have comments to make, please send them to the Editor, and we will publish them in a Letters to the Editor column

What's news with neutrinos?

When I studied Physics in the early 1980s Hugh Webster, a Tasmanian who had been a student of Chadwick at Cambridge in the early 1930s, was the Professor of Physics. Not surprisingly, our practical classes in Atomic Physics included experiments which duplicated the 1897 experiments of JJ Thomson to determine of the ratio of charge to mass of the electrons; the photo-electric effect (discovered in 1887 by Hertz, rediscovered by Lenard in 1902, and explained by Einstein in 1904 in terms of wave-particle duality ($E = h\nu$)); optical spectroscopy using an electrical discharge in hydrogen to test Bohr's 1913 model of the hydrogen, and similar studies of other gases to compare the results of the later theories of Pauli and Dirac (1924 & 1929). These theories were based on the concept that electrons had a magnetic moment (spin) which could interact with the magnetic moment caused by the orbital electrons, thereby creating new energy levels within the atom, and therefore more emission/absorption lines in the optical spectra.

In Nuclear Physics/Radioactivity, our textbook was JD Stranathan's *Particles of Modern Physics* (1942, McGraw Hill). The class undertook all the experiments described by Stranathan observing the properties of α-particles, β-particles, and γ-rays establishing that there were, respectively: stripped helium atoms (He^{2+}), electrons (e^{-1}), and high energy electromagnetic waves. Cosmic rays, and the spatial distribution of arrival in Australia were under investigation by members of the Physics Department staff, and formed part of the curriculum.

We did not, however, have the opportunity to duplicate Chadwick's (1932) experiment which demonstrated the existence of the neutron. In that experiment a polonium source of a-particles was enclosed in a can with a beryllium cover. He used a scintillation detector. Some activity could be seen of the surface of the scintillator. Insertion of carefully rolled silver sheets, calibrated for thickness, enabled the range of penetration and therefore

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the energy of the neutral radiation to be assessed. The energy of these particles was found to be ~5 MeV. Insertion of a sheet of paraffin changed the nature of the particles reaching the detector. Initially it was thought that the observed particles were γ-rays, but mass of the γ-ray photon is insignificant compared with the mass of the particle reaching the detector. These particles were positively charged and similar in mass to the proton. It was concluded that the particles detected were protons knocked on from the hydrogen-rich paraffin in billiard-ball-like collisions with the particles emitted from the beryllium. The interaction of the a-particle with the beryllium had caused a nuclear transmutation ($^{4}He + {}^{9}Be \rightarrow {}^{12}C + {}^{1}n$). The new particle which was electrically neutral and about the same mass as the proton was named the *neutron.*

Unlike the other then-known particles of modern physics……the proton, the electron, the photon (γ-ray), the a-, and β-rays……the neutron was unstable when it was not bound to a nucleus, and had a half-life of ~ 10.3 minutes. At first sight the decay process seemed to be: $^{1}n \rightarrow {}^{1}p + e^{-}$. But the directions of emission of the proton and the electron were not collinear. This implied that a third particle was involved in the scattering process. Applying the laws of conservation of charge and conservation of momentum led to the conclusion that the third particle had to be neutral, with a rest-mass close to zero. Bethe (~1938) named this new particle the *neutrino* (little neutral one). The neutrino was to remain unobserved until after World War 2.

In fact, the neutrino has never been observed directly. Since it has no charge it can only be observed through the interaction of its mass with other nuclei. It does, however, have angular momentum (spin = 1/2). Balancing the decay equation for conservation of momentum, charge, and angular momentum, led to the equation: ($^{1}n \rightarrow {}^{1}p + e^{-} + {}^{a}\nu_{e}$). The neutrino has to have a spin of (-1/2) and is therefore an anti-neutrino: ($^{a}\nu_{e}$) is the symbol I use to represent the anti-neutrino. Usually, when physicists write about neutrinos, they do not discriminate between the neutrino and its anti-particle in their discussions. The only difference between the two particles is that the neutrino is a matter wave of clockwise chirality about the direction of propagation, and the anti-neutrino has anti-clockwise chirality.

The neutrino was shown to exist experimentally in 1956, by Cowan and Reines using the neutrino radiation flux from a fission reactor. Free neutrinos are abundant in a nuclear reactor: about 10^{18} /s.m^{2}. Free neutrinos from the core of the reactor were collimated to a large cylindrical vessel filled with liquid scintillator (distilled water with $CdCl_2$ dissolved in it). The outputs of ninety photomultiplier tubes were tuned to look for the product of the inverse β-decay interaction between the anti-neutrinos with the protons in the water, ($^{a}\nu_{e} + {}^{1}p \rightarrow {}^{1}n + e^{+}$). A prompt positron annihilation event followed ($e^{+} + e^{-} \rightarrow 2\gamma$) together with the capture of the neutron by the ^{108}Cd ($^{1}n + {}^{108}Cd \rightarrow {}^{109m}Cd \rightarrow {}^{109}Cd + \gamma$). The coincidence of γ-rays from the positron annihilation event with the neutron capture event demonstrated that the antineutrino-proton event had taken place.

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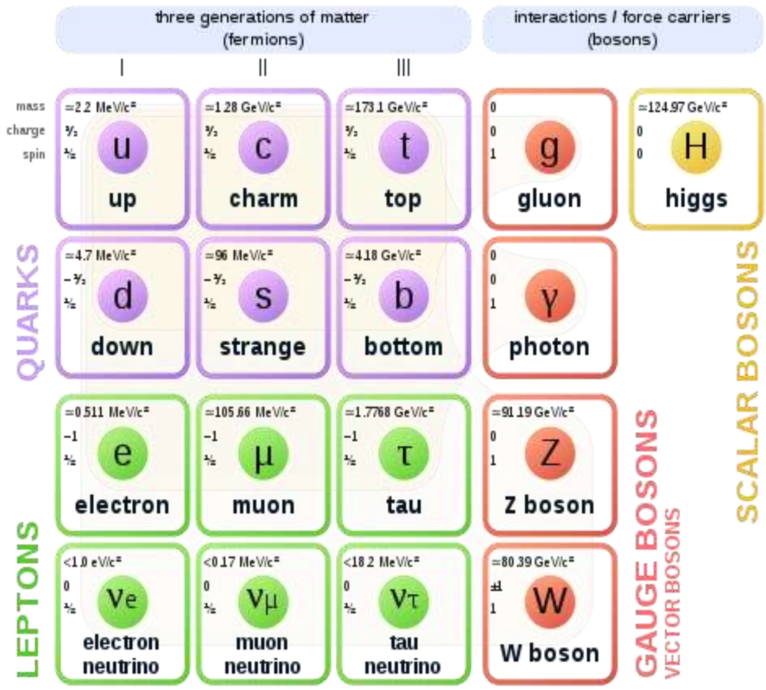
I cannot in this brief note give a detailed explanation of the ***Standard Model of Particle Physics***. In the following table I show the known particles and the families to which the individual particles belong.

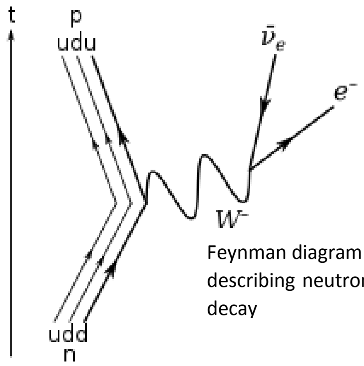


Of the stable particles in Stranathan's book only the ***electron*** is listed in the table.

($T_{1/2}$= 6.6 x 10^{28} years): mass = 0.511MeV/c^2; charge = -1; spin = $\frac{1}{2}$.

The ***proton*** ($T_{1/2}$ = 2.1 x 10^{21} years) is a composite particle made up of two up quarks (charge = 2/3; spin = 1/2) and one down quark (charge = -1/3; spin = 1/2) bound by a strong force-generating particle, the gluon (spin = 1).

The ***neutron*** is unstable ($T_{1/2}$ = 10.3 minutes), unless it is bound to a nucleus. It comprises one up quark and two down quarks bound by a gluon. The decay of the neutron is depicted by a Feynman diagram shown here. The W^- boson, formed by the mass-energy difference between the down- and up- quark, decays immediately into an electron and an anti-neutrino. This is the standard explanation for the β-decay of radioactive materials.



Feynman diagram describing neutron decay

Neutrinos emitted by stars

In the late 1930s both von Weizäcker (1937, 1938) and Bethe (1939) had published papers proposing that the energy production mechanism in stars was thermonuclear fusion, and the existence of the neutrino played a significant role in this process. The proton-proton interaction in the fusion mechanism is complex, but essentially: in an environment where the extreme heat has ionized all the atoms present, the high (gravitational) pressure compresses the constituents sufficiently close to overcome for any electrostatic forces. In this environment collisions can occur such that: $4\,{}^1H_1^+ + 2e^- \rightarrow {}^4He_2 + 2\nu_e + 26.73MeV$. There are several intermediate steps in this so-called (pp) reaction. At the time the concept of hydrogen fusion was a wild notion, a dream. But during World War 2 man-made thermo-nuclear fusion became a reality….hydrogen fusion was no dream.

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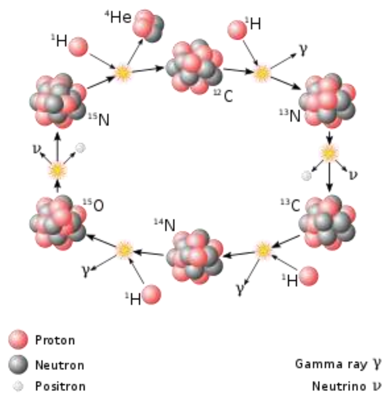
After the war Hoyle (1946) produced a seminal paper on *the synthesis of elements from hydrogen* in stars. From this a *Standard Solar Model* evolved. For most stars the so-called (pp) model is the prime source of energy.

However, another mechanism for energy generation exists….the so-called CNO or Bethe-Weizäcker cycle (Bethe, H (1939 Phys Rev **55**(5) 434-450). This cycle comprises a set of reactions in which four ^{3}H nuclei ultimately combine to form ^{4}He with carbon, nitrogen, and oxygen as catalysts and intermediate products.

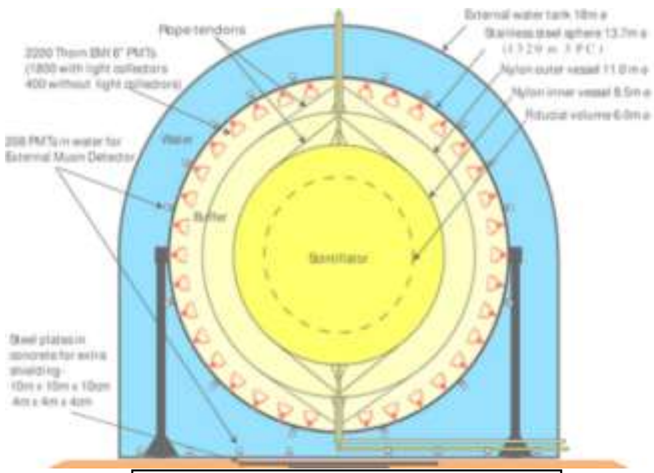


The relative importance of the two mechanisms depends mostly on the stellar mass and on the *metallicity*—the abundance of elements in the core that are heavier than helium. Because the CNO cycle relies on these heavy elements, the neutrino flux scales with the abundance of metallic atoms in the solar core at the time of the star's formation.

In the 1960s the neutrino flux from the sun was estimated to be about a third of that expected from the *Standard Solar Model*. But this discrepancy occurred to be because the emission of two other leptons, the muon (Anderson, 1936) and the tau-meson (Perl, 1974-1979), had not been taken into account. Each of these leptons decays to form an electron, a neutrino, and other neutrinos, named ν_μ and ν_τ respectively. These neutrinos have different masses from ν_e, and it was speculated that the neutrinos might oscillate between the three energy states in their passage through space. Experiments conducted separately at the Sudbury Neutrino Observatory and the Superkamiokande Observatory in 1998 have subsequently verified this speculation.

Solar Neutrinos

The neutrino flux from the sun is about 7 x 10^{14} /m^2 at the earth's surface. The Borexino project seeks to measure directly the flux of solar neutrinos of all flavours (e, μ, τ) emitted by ^{7}Be neutrinos by using an ultra-pure liquid scintillation detector. The scintillation material is psuedocumene (PC) containing 1.5g/l of fluor 2,5-diphenylazole. The Borexino project construction phase was completed in 2006 and the facility commenced data acquisition in 2007. The project is located in underground laboratories under the Gran Sasso Mountain in Italy.



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Solar neutrino observatories are often constructed deep underground or in the ocean to separate the highly penetrating radiation from the sun and other cosmic sources.

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The surrounding environments for these experiments have to be mechanically stable and have a low level of natural radioactivity.

The Borexino instrument is onion-like in construction. At its core is a sphere containing 287 tons of ultra-pure organic scintillator which is surrounded by an internal buffer of 1000 tons of purified organic solvent buffer, which in turn is shielded by 3500 tons of deionised water. The whole assembly has to be isolated form mechanical vibration to prevent micophonic effects from occuring in the 2200 photomultiplier tubes (1800 light gathering, and 400 non-light gathering (used to provide reference/background data)). At the interface between the solvent buffer and the water 208 muon detectors are installed. Other significant construction details can be the schematic diagram (above).

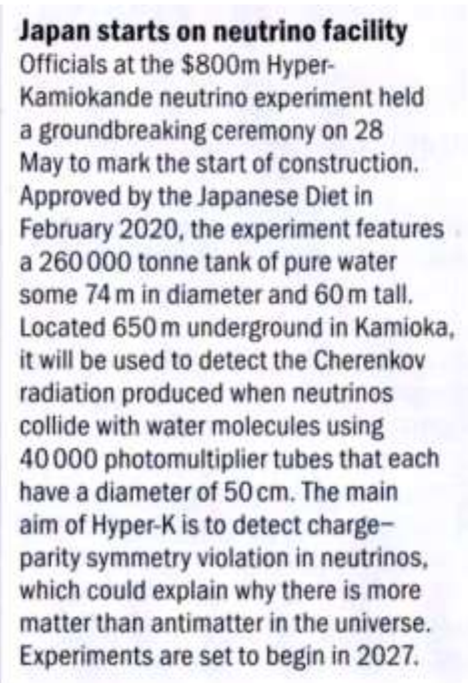
Eliminating or militating against the effects of background radation is important; especially ^{210}Bi and ^{11}C, which have the same energy spectra of CNO neutrinos, as well as those from the (pp) process which occurs in the solar neutrino flux. Count rates are low: ~2100 events per day in the whole volume of the scintillator. Nevertheless, the statistical reliability of the results is at the 5σ level, which is sufficient accuracy to confirm that the CNO cycle is the source of some of the neutrinos reaching the earth, and that their contribution to the solar neutrino flux was 1%. Physics World (Physics World **34** January 2021 p6) was able to report:

Borexino spots solar neutrinos from elusive fusion cycle.

Success does not guarantee longevity, however, because 1t was reported (Physics World **34** November 2021 p15) that the Gran Sasso experiment is to shut down. It is thought that leaks of pseudocumene from the detector could contaminate ground water on which neighbouring towns depend. **Vale Borexino.**

Japanese plans for the future

Japan has recently committed $800m to the Hyper-Kamiokande facility. This will be sited 650m under Kamioka, Japan. Its detector will be a cylindrical tank, 74m in diameter and 60m tall, filled with pure water having a mass of 260,000 tons. Cherenkov radiation, which is produced when neutrinos collide with the water molecules, will be detected by 40,000 photomultiplier tubes.


Japan starts on neutrino facility
Officials at the $800m Hyper-Kamiokande neutrino experiment held a groundbreaking ceremony on 28 May to mark the start of construction. Approved by the Japanese Diet in February 2020, the experiment features a 260 000 tonne tank of pure water some 74 m in diameter and 60 m tall. Located 650 m underground in Kamioka, it will be used to detect the Cherenkov radiation produced when neutrinos collide with water molecules using 40 000 photomultiplier tubes that each have a diameter of 50 cm. The main aim of Hyper-K is to detect charge–parity symmetry violation in neutrinos, which could explain why there is more matter than antimatter in the universe. Experiments are set to begin in 2027.

The aim is to detect charge-parity symmetry violations in neutrinos, and determine why there seems to be more matter than anti-matter in the universe.

And Japan looks again at the past

Sometimes old data can provide new insights into the way the universe is evolving. Reviewing old data from the Kamiokande II project Yuichi Oyama, a scientist at the KEK in Japan has said that two experiments may have

Continued next page :

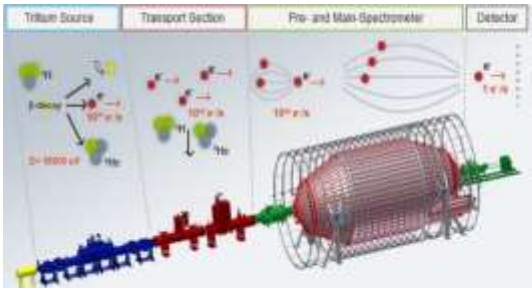
intercepted high-energy n**eutrons from the Supernova event, SB1987A observed on** 23 February 1987. The particles were detected both in Japan and at the Irving-Michigan-Brookhaven (IMB) laboratory in the USA. (Physics World **34** October 2021 p9).

The light emission peaked in May and 25 of the neutrinos were detected within 13 seconds of arrival of the visible image. But these were relatively low energy neutrinos (~ 10 MeV/c^2), much lower than the energies predicted ought to occur in the year after the supernova event (~ 10 BeV/c^2).

Pions produced in the atmosphere by the cosmic ray flux decay to produce anti-muons also produce neutrinos. To overcome the spurious effect caused by atmospheric muons/neutrinos the data was analyzed to take account only of particles arriving from below the detector. Only these neutrinos would have the ability to penetrate through the earth and arrive at the detector. Oyama screened the data according to the criteria that neutrino arrivals were restricted to a time window of 11 August to 20 October 1987 and to an angle of acceptance within 10° of the direction of SN1987A. After combining the data only 4 events met these criteria. After exhaustive statistical analysis Oyama found that odds of them **not** originating in SN1987A to be 0.27%.

There are those who doubt the validity of Oyama's results. But they will have to wait for another supernova event occur to have the data to dispute his findings …and that may take some time to happen.

What is the mass of a neutrino?



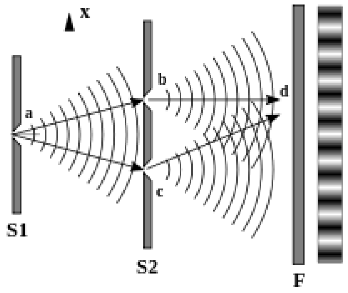
The mass of the neutrino can be determined by measuring the energy spectrum of the emitted neutrinos and finding what the least detectable energy is. A schematic diagram of the KATRIN facility at Kahrlsruhe illustrates this. The β-decay of tritium gives an anti-neutrino and an electron. The electron is conducted *via* a transport system into a gigantic (10m diameter) electron spectrometer and into a detector array. A retarding electric field is applied until electrons can no longer be detected. The lowest mass of the neutrino was found to be **1.1eV/c^2.** (*Aker, M. et al. Preprint https://arxiv.org/abs/1909.06048 (2019)).*

The existing theory of β-decay is based on the assumption that the rest mass of the neutrino is zero. But what if it has a mass? Would this change our understanding of the Standard Model of Particle Physics?

*Commentary by Dudley Creagh. Acknowledgements are given to Physics World who reported items described in this article. The picture of the supernova is from Physics World (2021)**34**10 p5. The report of the Japanese facility is from Physics World (2021)**34** 7p5. Diagrams of the Standard Model of Particle Physics and the Feynman diagram of neutron decay are from Wikipedia. The schematic diagram of the Borexino detector is from Ianni, A (2010) NIM **A67** 488-491. The schematic of the KATRIN facility is from the Kahlsruhe Institute of Technology.*

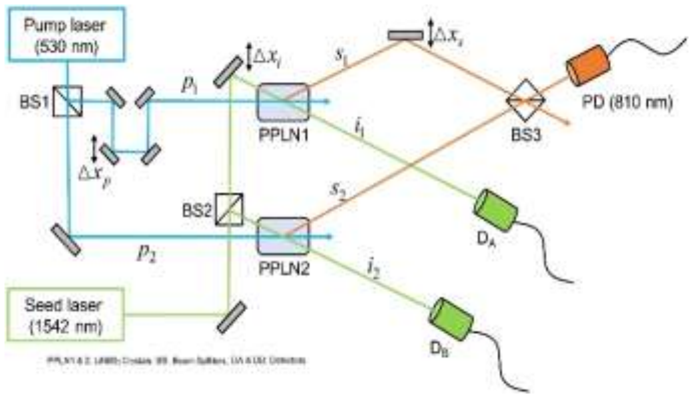
Item 2 : next page

Quantifying wave-particle duality



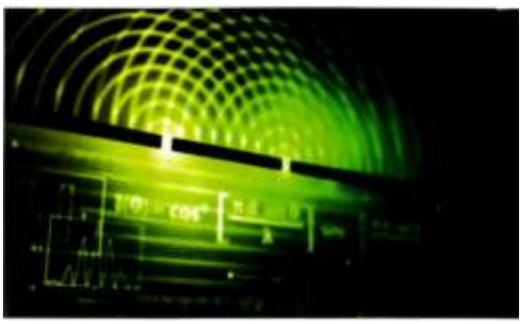
The Young's double slit experiment (~1805) proved that light waves emanating form a single source can produce interference patterns. Since then scientists like Planck, Einstein, and Schrodinger speculated that particles could interact to form interference patterns. De Broglie was the first to demonstrate that electrons could interact to produce interference patterns in his doctoral studies at the Sorbonne (deBroglie, L (1923) Nature **112** p2815). Later, Zellinger *et al* were able to demonstrate single and double slit interference using cold neutrons (Zellinger et al (1988) Rev Mod Phys **60** p1067).

Recent experiments in South Korea have shown new light on the interaction of photons using laser beams interacting with two crystals of lithium niobate. Lithium niobate is axially birefringent and laser pulses are split into two beam paths (see Yoon *et al* Yoon, TH, Cho, MH (2021) Sci. Adv. 7 abi9268) which travel along the axis of birefringence. A description of the interferometer system and the way it is used is too detailed for me to describe here.



The entangled nonlinear bi-photon sources comprise two spatially separated type 0 phase-matched spontaneous periodically poled lithium niobate crystals which are the entangled signal single-photon generation sources and the conjugate idler photons acting like which-path detectors. One of these beams was directed into an interferometer to set up the traditional interference effect and the other was used to determine its particle character. Because the photons are produced together they form a single quantum state described by both the wave and particle measurements.

Changes in the intensity of the beams independently altered the ability of the crystals to emit photons. When one of the was very likely to emit photons the interferometer pattern was barely visible….indicating that the pattern was mostly particle-like. If the emission probabilities were equal the interference was sharp. The degree of *particle*-ness and *wave-ness* can be controlled.



Controlling these characteristics can enable determination of the entanglement of the photons with the detectors that identified their path.

This ability has implications in the development of quantum devices. Minhaeng Cho, directorof the IBS Centre for Molecular Spectroscopy at Korea University has been quoted as saying:

"***this could be a useful way to engineer states for quantum information***".

Commentary by Dudley Creagh*. The impetus to write this comes from an item by Karmela Pedavic-Callaghan in Physics World* ***34*** *October 2021 p6. The experimental setup is taken from Yoon, TH, Cho, MH (2021) Sci. Adv.* ***7*** *abi9268. The cooperation of Sci. Adv. in making access to this paper is much appreciated.*

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9: --
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