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1966
INSTRUMENTATION
APPARATUS
EXHIBITION
24th – 26th August

Under the direction of the Australian Institute of Physics (N.S.W.).

Recent Advances
in Instrumentation
Apparatus

is the thesis of the CONVENTION and will be demonstrated at the EXHIBITION by the leading companies in this specialised field.

PLACE: University of N.S.W., Day Avenue, Kensington.

TIME: 10 a.m. to 6.30 p.m.

TICKETS: On application and stamped addressed envelope, two complimentary tickets will be issued. Note: All N.S.W. members of the Institute will be sent a ticket.

APPLY: R. J. Glover, Exhibition Administration, P.O. Box 129, Mosman, N.S.W.
TELEQUIPMENT NEW OSCILLOSCOPE D53

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The D53 shares with the D43/S43 a wide range of plug-in Y amplifiers, thus forming a versatile and economical system.

**General Specifications**

Y Amplifier: Frequency, sensitivity and attenuation dependent on the plug-in Y amplifier used.

Time Base: 22 calibrated speeds 0.5μ Sec - 5 Sec/cm. Sweep Delay up to 5m Secs and up to 50m Sec/cm. Single shot facility with lockout. Triggering: Int, Ext, DC-AC slow — to remove DC component: AC fast — to remove LF components, HF, TV line/frame.


C.R.T.: Split beam rectangular mesh type tube PDA at 8.5KV. Display (each beam) 6cm x 10cm (wide). Z modulation input.

**PLUG-IN Y AMPLIFIERS**

<table>
<thead>
<tr>
<th>A General Purpose</th>
<th>B Differential</th>
<th>C Ultra Hi-gain CD</th>
<th>D General Purpose</th>
<th>G General Purpose</th>
<th>H Wide Band HD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth</td>
<td></td>
<td>Delay Version</td>
<td>Monitor</td>
<td>Delay Different.</td>
<td>Delay Version</td>
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<tr>
<td>DC-15Mc/s</td>
<td>DC-7.5Kc/s</td>
<td>DC-15Mc/s</td>
<td>2.5Mc/s-32Mc/s</td>
<td>DC-5Mc/s</td>
<td>DC-25Mc/s</td>
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<td>DC-8Mc/s</td>
<td>DC-8Mc/s</td>
<td>DC-8Mc/s</td>
<td>32Mc/s-75Mc/s</td>
<td>DC-5Mc/s</td>
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<tr>
<td>Sensitivity</td>
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<td>100mV/cm</td>
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<tr>
<td>Rejection Ratio</td>
<td>Max. 10,000:1</td>
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<tr>
<td>Attenuator</td>
<td>Calibrated 12 position Freq. Comp. &lt;5% As type A As type A As type A</td>
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<tr>
<td>Accuracy Input</td>
<td>1 Meg 40pF</td>
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<td>Impedance</td>
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<td>Rise Time</td>
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Note: All Y amplifiers interchangeable between D43/S43 and D53 except CD and HD (D53 only).

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- Available in flat pack and industrial pack

**Integrated Circuits**

<table>
<thead>
<tr>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>One SN7420 Dual 4-input positive NAND gate</td>
</tr>
<tr>
<td>Two SN7450 Dual EXCLUSIVE-OR gates with expander inputs</td>
</tr>
<tr>
<td>Four SN7470 Single-phase J-K flip-flops</td>
</tr>
</tbody>
</table>

**Breadboarding Sockets**

<table>
<thead>
<tr>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Four MPC-1 14-pin Mach-Pak sockets</td>
</tr>
</tbody>
</table>

**Total value:** $71.50

**SPECIAL INTRODUCTORY PRICE:** $49.50

**Sample Applications**

- 4-bit Binary to Gray-code Converter
- 4-bit Binary Comparator
- Divide-by-5 Counter
- Binary Coded Decimal Counter

**SERIES 72 AMPLIFIERS**

**Integrated Circuits**

<table>
<thead>
<tr>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>One SN723 General purpose differential amplifier</td>
</tr>
<tr>
<td>Three SN724 General purpose operational amplifiers</td>
</tr>
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</table>

**Breadboarding Sockets**

<table>
<thead>
<tr>
<th>Value</th>
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<tbody>
<tr>
<td>Two MPC-1 14-pin Mach-Pak sockets</td>
</tr>
</tbody>
</table>

**Total value:** $84.20

**SPECIAL INTRODUCTORY PRICE:** $49.50

**Sample Applications**

- Variable gain—a-c amplifier
- Stable gain circuits
- Isolation amplifiers (buffer)

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Recent Developments in Atmospheric Geophysics

V. D. Hopper

Physics Department, University of Melbourne.

The text of this paper was presented as the Chairman's Address to the A.I.P. Geophysics Group at Canberra on April 20, 1966.

The level of research in meteorology and atmospheric physics during the past twenty or so years has risen remarkably. The basic reason is that, prior to this period, efforts particularly in meteorology were of an applied nature for the most part. The meteorologists throughout the world were engaged in forecasting tomorrow's weather and the forecasters were remarkably accurate according to today's standards, bearing in mind the additional data that is now available. There was a pretty clear-cut region that the meteorologist considered important — for instance, all measurements of temperature, pressure and wind made with balloons ceased at 67,000 feet even though the balloon often exceeded that height. Even if the observer was interested in making additional measurements it was not possible as his day's time-table was full with routine tasks. The amount of data recorded depended on the prescribed tables to be completed rather than the performance of the instrument or facilities. The number and accuracy of the observations depended on the closeness of population and financial resources of the country. Detailed observations were available for England and regions in the northern hemisphere but very few for the southern hemisphere. Research was left in general to Universities or Government departments of scientific research, e.g., C.S.I.R.O., D.S.I.R., Cambridge Research Laboratories, etc.

One of the most important stimuli as regards atmospheric geophysics was the I.G.Y. — the International Geophysical Year, which in fact covered eighteen months from July 1, 1957, to December, 1958. Australian scientists took part in investigations in areas of geomagnetism, seismology, ionosphere, aurora and airglow, cosmic rays and solar astrophysics.

There was active collaboration amongst scientists. The Australian Bureau of Meteorology extended their upper air observations to the maximum possible by balloons at that time. The effective burst height was increased by some 15,000 feet by the insertion of simple valves in the neck of the balloons — a technique which has been developed by the University of Melbourne in its efforts to get level flights using meteorological balloons for cosmic ray studies. Many observations exceeded 120,000 feet and all results were recorded.

The stress of the I.G.Y. was its international character. Measurements were made wherever possible to extend the coverage over the globe. The Antarctic was visited by people of many countries and most of the bases are still in service. Still the coverage of the southern hemisphere was an order or two of magnitude less than for the northern. This was of course due to the area involved, the sparseness of population and lack of finance. One development during the I.G.Y. did, however, show promise that such a situation might soon disappear. This was the ability of man to launch satellites which made regular orbits of the globe each 90 minutes. A coverage of the globe was now possible — equal time is spent by the satellite in each hemisphere and if the satellite is equipped with sensors it is feasible to have an equal number of measurements of the northern and southern hemispheres.

During the I.G.Y. the sunspot activity broke all previous records. The average monthly sunspot number reached 201, exceeding by 28 per cent. the highest number of previously recorded years. The next solar maximum is expected in 1969, but a comparison of measurements of the I.G.Y. with these, during the time when the solar network is a...
minimum, is very important. Thus a further concentration of activity has occurred during the I.Q.S.Y. — the International Quiet Sun Years, January 1, 1964, to December, 1965. The meteorological programme during the I.S.Q.Y. concentrated upon phenomena at high altitudes, that is above the 100 millibar region or in the upper 10% of the atmosphere. An effort is being made to couple the effects at high altitude with the conventional lower region of the meteorologists.

The subject of sunspot cycle influences on weather and other phenomena at the bottom of the atmosphere is controversial. However, it has been realized that the ionosphere is under solar control and the upper atmospheric temperatures, as revealed by satellite data, are influenced by solar activity. At 1000 km, the kinetic temperature during solar maximum was of the order of 2000°K but during solar minimum it had dropped to 700°K. Significant energy transfer is achieved through solar particle fluxes and it is necessary, in the construction of mathematical models of the atmosphere, to consider the energy transfer that occurs vertically as well as horizontally. Thus a knowledge of solar fluxes is included in the research fields of the meteorologist.

As well as the solar fluxes, there are other phenomena which might influence the weather, e.g., solar and lunar gravitational effects. A study over 50 years indicates that the heaviest rainfall occurs about two to three days after full moon or new moon. There is a 26-month upper stratosphere temperature and wind strength oscillation which requires explanation. This may be related to some beat effect of the various effects such as heating by the sun and gravitational lunar tides. There is considerable ignorance regarding movements in the stratosphere. Some interesting but as yet unexplained results have been obtained at Mildura by the balloon air sampling team. A study was made of the C139 which had been injected into the atmosphere by a rocket-borne nuclear device at 400 km (17°N) in 1962. It was found that the maximum concentration after two years was in the southern hemisphere rather than the northern.

A satellite carrying nuclear power re-entered the atmosphere over India in 1964. After four months the maximum concentration of Pu239 also appeared in the southern hemisphere. The interpretation of such distribution is not possible until further knowledge of stratospheric simulation is available.

Weather satellites promise to be valuable assets for forecasting as well as completing the global picture of weather features such as clouds, tornadoes, rainfall and cold and warm fronts. Six years after the Tiros I was launched, several hundred pictures of the earth and cloud system were taken. These provided warnings of weather changes and confirmed certain theoretical predictions such as the spiral structure of cloud systems in temperate regions. A cellular pattern was observable over tropical areas. It is observed that long period eddies occasionally develop downward from certain mountain and oceanic islands. The main drawback for the Tiros satellites was that the optical resolution was no better than 10 kilometers. It was also a difficult process piecing together the various pictures — particularly in ocean regions where there were no landmarks to position the photographs.

The later satellites have improved camera systems. Infra-red detectors are carried to provide night-time data on cloud distribution and height, temperatures of clouds and of the earth surface outgoing radiating water vapour and carbon dioxide concentration in air masses through which the sensor is looking. These improved systems combine Medium Resolution Infra Red (MRIR) and High Resolution Infra Red (HRIR) systems.

The HRIR sensor on Nimbus I has already produced cloud pictures as good as those from the earlier television cameras. With continued improvement these may function effectively in daytime to supplement the visible light pictures.

Since Tiros IX and including the Nimbus Series, the meteorological satellites have been stabilized to point the camera earthwards when taking pictures. Nimbus HRIR pictures are furnished with lines of latitude and longitude overlaid on the positive print. Modified polar orbits are used which permit more complete coverage of the earth.

Other information to supplement the balloon and satellite data come from meteorological rockets. Minor constituents such as ozone, water vapour and particulates significant in the radiation balance process are being studied and thermal radiation measurements are being made throughout the atmosphere.

Preliminary studies are being made in the southern hemisphere of the so-called Ghost Balloon Programme. These are light weight pressurized balloons capable of floating for months, it is hoped, at constant levels from 10,000 to 40,000 feet. They carry radio equipment which transmit information of position, height, temperature and humidity. It is intended to launch several hundred or even thousands of these balloons which will be tracked as they drift around the world in the atmosphere. Later it is planned that a satellite will interrogate and track these balloons and provide regular information in regions not serviced by the regular world network.

It is essential to co-ordinate all this information and rapidly make it available to the meteorological stations throughout the world. The W.M.O. has decided to establish a World Weather Watch. It is to be an organization by which national centres will install facilities which will assist neighbouring as well as their own centres. Three capital cities have been designated as World Meteorological Centres (W.M.C.’s); Melbourne, Moscow and Washington.
One function will be to collect the conventional and satellite data on a global basis and transmit this information to others.

The use of computers in such work is obvious and the Australian Bureau of Meteorology is taking steps to see that it is performing its important function satisfactorily. A further feature will be the global telecommunication system involved in which line, submarine and radio relay will be used as well as satellites. There will be a trunk circuit — Melbourne-Washington-Moscow — of the duplex type, i.e., it will be possible to transmit high speed facsimiles simultaneously in either direction. A possible future development will be the placing of a meteorological observatory on the moon's surface.

Another organization is the newly created Environment Science Service Administration (E.S.S.A.). This links together seismology, oceanography, meteorology, hydrology, geomagnetism, geodesy, aeronomy and solar physics. There is a growing recognition that the ocean, the lower and upper atmosphere and the earth all interact and help to determine each other. New tools such as satellites, electronic computers and high speed communication systems make it possible to probe the physical environment throughout the globe and also collect, process, analyse, disseminate and store environmental data. E.S.S.A. is under the U.S.A. Department of Commerce and, as a first step, will concentrate on studies around the U.S.A. There are sufficient scientists in Australia interested in these features to provide a similar organization here which could link with the American counterpart.

Of particular interest to the upper atmosphere are studies of geomagnetism. An accurate determination of the configuration of the earth's magnetic field is important as it governs all charged particle phenomena in the vicinity of our planet. It controls the orbits of cosmic rays and prescribes limited impact zones in which particles may arrive from the sun. It gives rise to the Radiation belts.

In addition to ground based and air plane magnetometers, special equipment for measuring magnetic variations is in operation. This is the micropulsation equipment and a number of stations exist in Australia and more are being planned for the Antarctic region by the Antarctic Division. Rocket and satellite-borne instruments are probing the magnetosphere and beyond. The boundary region of the magnetosphere, the magnetopause, and the transition region between the sun's atmosphere and the earth's is being explored.

The Auroral light is being investigated by radio waves, balloons, rockets and satellites. The study of conjugate point effects is of considerable importance. A nuclear device was exploded in the upper atmosphere and it is believed to have created two simultaneous auroras—in the northern and southern polar regions.

The geocorona is a ring of hydrogen gas which encircles the earth and is detectable through the Lyman α light which it emits. This is subject to distortion by the solar wind past the earth and there is a useful adjunct for the study of solar plasma. Other airglow emissions are yielding information in the structure and chemical composition of the upper atmosphere. Rocket-borne instruments provide vertical height profiles and satellites permit monitoring of spatial and temporal variations.

Several fruitful lines of research are developing in ionospheric physics mainly due to the applications of satellites and rockets. The topside sounding method combined with bottomside sounding is now giving more detailed information of the variability of the ionosphere and the influence on it of the solar wind. Radar sounding of the ionosphere reveals details on electron and ion temperature. Whistles and ionospheric waves are providing information on the outer ionosphere and the entry of charged particles into the geomagnetosphere.

The lower end of the energy spectrum of galactic cosmic rays is being investigated in considerable detail. The sun's solar plasma exerts a modulating influence on cosmic rays. During sunspot maximum, a greater shielding effect, caused by this modulation, is present. The nature of the modulation process is of considerable interest to the physicist. Solar-produced particles are being investigated by means of apparatus on the ground, by balloon-borne instruments launched in the polar region, and by instrumentation aboard satellites and rockets. Many varied investigations are being made on the trapped radiation belts using satellite-borne instruments.

Perhaps the most important developments in cosmic ray research are not immediately of interest to the upper atmosphere physicists. These developments involve the search for the origin of cosmic radiation by looking for γ-ray and X-ray sources. Since charged particles are deviated by magnetic fields and these are shown to exist in intergalactic regions, it is necessary to study the non-charged components such as γ radiation. Some elaborate experiments are being designed to attack this problem and it is expected that several experimenters from the U.S.A. and U.K. will join Australian groups during the next few years. The importance of the southern hemisphere, with its view of the central region of our galaxy, cannot be overstressed. Satellites, however, when sufficiently accurately stabilized, will provide valuable bases for such experiments. Balloon-borne and satellite-stabilized platforms are necessary for accurate work and such developments will be valuable for a continuing study of the sun and the planets.

X-ray measurements of the sun have been made from satellites in both the maximum sunspot period and the minimum sunspot period. During the sunspot minimum the X-ray emission in the shortest wave length band 2.8Å was too faint to detect. At
Infra-red measurements of Jupiter show the pressure of deep methane bands and a band due to H₂. The mean temperature of the atmosphere is approximately 175°K but the radio measurements suggest an upper atmosphere temperature of 2800°K.

Of the remaining planets, Mercury has no atmosphere as a result of its proximity to the sun. The outer planets have dense atmospheres but their distances are such that it will be difficult to obtain direct radio information from balloons floating in their atmospheres.

I think that I have given sufficient information to prove that there is an active field of research proceeding in the Geophysics of the Atmosphere. There is also considerable interest shown by young research students in entering these exciting fields of research. It puzzles me that there is not a similar rush to attack problems in Geology and Terrestrial Geophysics. I believe this is coming, but the essential feature is to attack such subjects from the research side rather than from the undergraduate aspect. I believe that the University should give a basic undergraduate groundwork to the future geophysicists in physics, chemistry, some biology, mathematics, computer theory and statistics. After two or three years of such undergraduate courses, introductory lectures should be given in geology, meteorology, seismology, hydrology, oceanography, etc. If during the postgraduate years specialized lectures in the geophysical aspects of special interest may be taken, we will assure by this method that we have graduates well equipped in the fundamentals of science as required in our modern age.

Coming Events

2nd A.I.P. Summer School — Canberra

The Second Summer School will be held in Canberra from 23rd January to 27th January, 1967, inclusive. The programme will include review and invited papers in Mathematical Physics and Geophysics, and the invited speakers will be announced at a later date. The Mathematical Physics programme will be held in conjunction with the 7th Summer Research Institute of the Australian Mathematical Society. Accommodation will be arranged for participants in Residential Colleges and financial assistance will be given to a number of graduate students wishing to attend.

Further details will be published in the Australian Physicist in the near future. Any enquiries may be directed to Dr. R. MacDonald, Dept. of Physics, School of General Studies, A.N.U.

Symposium on Experimental Stress Analysis

Melbourne Division of the Institution of Engineers, Australia, is sponsoring a Symposium on Experimental Stress Analysis to be held at Monash University on 18th and 19th August, 1966. The purposes of the Symposium are to impart knowledge of modern techniques of experimental stress analysis in a form which can be readily assimilated; to bring together people working in the field to discuss problems of mutual interest; to consider the requirements for future meetings where particular aspects of the subject can be explored in greater depth by specialists. Details of the Symposium are given in a leaflet which may be obtained from F. Frueh, Convener of the Symposium, Institution of Engineers, Australia, Kelvin Hall, 55 Exhibition Street, Melbourne C.1, Victoria.
A Survey of Plasma Physics and its Application to the Production of Thermonuclear Power

P. W. Seymour

Department of Mathematical Physics, The University of Adelaide, South Australia.

An Introduction to the Plasma State

In relatively recent years scientists, engineers and technologists throughout the world have been paying increasing attention to a fourth state of matter—the plasma state. In terms of a simple, non-mathematical definition, a thermonuclear plasma is a very hot fully ionized gas in which the orbital electrons of the atoms have been stripped away from the positively charged nuclei, leaving, in the simplest case, a positive ion fluid and an electron fluid, coupled by collision processes, and having a common kinetic temperature in thermal equilibrium. At lower plasma temperatures some neutral atoms will be present. Of basic importance is the macroscopic charge neutrality of the plasma, a property which follows naturally from the above definition. Any process which tends to produce a significant imbalance of positive and negative charges in a given macroscopic volume element of the plasma gives rise to a strong restoring electric field in that region, and the charge separation is rapidly cancelled, mainly by electron motion, because the electrons are highly mobile relative to the much heavier positive ions. Evidently, one can expect plasma oscillations to occur in response to a small localized perturbation of the plasma, since, in view of their inertia, the mobile electrons will collectively overshoot their rest position, and hence oscillate to and fro in such a manner that average electrical charge neutrality is closely maintained in the plasma.

Considering temperatures in the Universe, a definite lower limit is, of course, the absolute zero of temperature. Above the absolute zero we pass through the low temperature of, say, liquid nitrogen at 77° Kelvin, and proceed towards the familiar temperatures of the earth’s surface. Here, considering, for example, a modern steel furnace, a temperature of some 2000°K is attainable. In the vicinity of the surface of the sun, where the temperature is above 6000°K ionization due to radiation is present. However, we have still not entered the region of thermal plasmas. It is at a temperature above some 10,000°K that we first encounter the thermal plasma, and it is perhaps a depressing thought that all matter becomes plasma if it can be made hot enough. The total plasma content of the Universe has been estimated at about 99.9%. At one million degrees Kelvin the experimental Zero Energy Thermonuclear Assembly ZETA takes its place. In the region of 20 million degrees Kelvin we have the sun’s centre. The sun is, in fact, a big controlled thermonuclear reactor, as distinct from the uncontrolled thermonuclear reactor, the hydrogen bomb. Finally, at temperatures of 100 million degrees Kelvin or greater, we have the dream of the future, the controlled thermonuclear reactor.

Contemplating our predicted total power requirements for the future in relation to present day resources, it is a fact that our reserves of the fossil fuels, coal and oil, are fast running out. Estimates suggest that fission fuels will last somewhere between twenty and twenty-five times as long as the fossil fuels, thus giving us several hundred years grace before these energy sources are exhausted. From a long term point of view it is evident at this stage that attempts must be made to tap a new source of energy, to meet the ultimate demands of the future.

The Production of Power by Fusion.

Fission of a heavy element, such as uranium, into a pair of lighter elements results in the production of energy because the average binding energy per nucleon (the generic term for the protons and neutrons forming an atomic nucleus) increases as we move in from each end of the periodic table of elements towards the centre. In building up the nucleus of a given element from an appropriate combination of protons and neutrons, it is found that the total mass of the complete nucleus is less than the direct sum of the individual proton and neutron masses. This mass discrepancy corresponds, through Albert Einstein’s equation \( E = mc^2 \), to the release of a significant amount of energy as the nucleus is formed —the binding energy. The mass discrepancy is small, but since the square of the light velocity approaches \( 10^{21} \) in numerical value, the energy release is large. Because the fission fragments correspond to elements nearer the centre of the periodic table, i.e., to elements with increased binding energy per nucleon, splitting the original heavy element results in the production of energy. Clearly, fusion of light elements would also result in the formation of an element closer to the centre of the periodic table, and hence to the production of energy due to the mass discrepancy. This is the possibility we discuss here, because a typical light-element fuel could be deuterium, of which we can obtain vir-
ually unlimited supplies from our oceans. Deuterium, the mass-2 isotope of hydrogen, is present in ordinary water to the extent of about one part in six thousand. On this basis the energy available from the fusion of approximately one eighth of a gram of heavy hydrogen obtainable from one gallon of water would be equivalent to the heat energy produced by burning some three hundred gallons of petrol!

Considering the fusion process in greater detail, imagine the nuclei of a chosen light element at a given high temperature, so that they are in ceaseless thermal motion. At relative velocities insufficient for fusion, the Coulomb repulsion is strong enough to prevent a pair of nuclei coalescing at an encounter. To make things as easy as possible, we choose a possible thermonuclear fuel having atomic number $Z=1$, the smallest possible value of $Z$. This minimises the Coulomb repulsion, and by increasing the kinetic temperature to a value beyond about $10^8$ K, it is found that the relative velocity of approach for a pair of nuclei can overcome the Coulomb repulsion effect to the extent that the short-range nuclear forces take over, and the particles fuse, with the production of energy by the process described above. Therefore, in a potential thermonuclear reactor we must arrange matters so that many encounters take place between the charged nuclei in a given, short time, to give them maximum opportunity to fuse or coalesce. For $Z=1$, it turns out that the proton-proton reaction is too slow on earth to be of practical use, and in fact, nuclear reactions between the mass-2 and mass-3 isotopes of hydrogen are of earthly interest: we have

$$D+D \rightarrow \text{He}^3+n+3.2\text{MeV}$$  \hspace{1cm} (1)

occurring with about equal probability, the energy being released as kinetic energy of the reaction products; and also

$$D+T \rightarrow \text{He}^4+n+17.6\text{MeV}$$  \hspace{1cm} (2)

In these nuclear reactions, D stands for deuterium, n for neutron, p for proton, He$^3$ and He$^4$ for the mass-2 and mass-4 isotopes of helium (He$^4$ also being termed an alpha particle), and T for tritium (the mass-3 isotope of hydrogen). The unit MeV corresponds to $10^9$ electron volts, where one electron volt corresponds to $1.6 \times 10^{-12}$ ergs, the energy acquired by an electron in passing through a potential difference of one volt. Sometimes kinetic temperatures are quoted in electron volts, and it is easily established that one electron volt is approximately equivalent to $10^6$ K. Tritium does not occur to any extent in nature, being radioactive, with a half-life of 12 years. However, to take advantage of the useful looking D-T reaction, we could possibly cloak our potential controlled thermonuclear reactor (hereafter abbreviated to CTR) with a lithium blanket, so exposing it to neutron bombardment from the neutron flux produced by

the first of the D-D reactions above: for suitably moderated or slow neutrons we have

$$\text{Li}^6+n \rightarrow \text{He}^3+4.4\text{MeV},$$  \hspace{1cm} (3)

suggesting that we can breed tritium and feed it back to the CTR for burning.

The reaction products appearing on the righthand sides of the above nuclear reactions consist of either charged particles alone, or of both charged and uncharged particles. Using the fact that momentum must be conserved in any nuclear reaction, a simple calculation shows that the energy released in a given case is distributed between the pair of product particles inversely as their masses$^2$. In the modern steel furnace mentioned earlier, the molten metal at a temperature of order $2000^\circ$K is contained by means of material walls. At the required thermonuclear plasma temperature of over $10^8$ K, material walls are not feasible for plasma containment. This is not for the often-quoted reason that the walls would vaporize and disappear—the power density appropriate for a thermonuclear plasma is, in fact, quite low, being in a typical case about 100 watts per cubic centimetre—but rather because contact with material walls would cool, and thus quench, the plasma. Controlled thermonuclear power became possible in principle when it was recognized that a plasma, which is an extremely good conductor of electricity, could theoretically be held in a suitable position by means of a very strong, appropriately shaped, magnetic field. An electric field fails in this role for several reasons, the most obvious of which is that an electric field configuration which suitably confined, say, the negative charged particles of a plasma in a suitable region will encourage the positive charged particles to move out of that region!

As will be seen later, if a deuterium plasma can be held in this magnetic furnace for just a few seconds, thermonuclear power becomes a practical possibility. However, the plasma turns out to be a restless, wriggling state of matter under these confinement conditions, and in trying to escape from the magnetic furnace it poses serious problems for the scientist, engineers and technologists.

The Elementary Mathematics of Plasma Containment

In the microscopic picture of plasma charged particle motions$^5$, the basic Lorentz force law leads to the conclusion that the charged particles spiral around the magnetic field lines with radius which varies inversely as the magnetic field strength, B, and with angular frequency which varies directly as B. For the choice of a tenuous plasma, in which, as an approximation, we neglect interparticle collisions, the influence of the magnetic field is such that it does not hinder the motion of charged particles along the magnetic field lines, but it does substantially impede the motion of charged particles transverse to these lines. By choice of a suitably
shaped confining magnetic field, the mechanism of containment in the microscopic picture can thus be visualized.

In the macroscopic picture, the statistical behavior of many plasma charged particles is sensibly governed by the linearized equation of motion for a neutral plasma in a magnetic field,\(^6,12\)

\[
\frac{\partial \mathbf{V}}{\partial t} = \mathbf{j} \times \mathbf{B} - \nabla p - \rho \nabla \phi, \tag{4}
\]

where \(\rho\) is the plasma mass density, \(\mathbf{V}\) is the plasma mean mass velocity, \(\mathbf{j}\) is the current density, \(\mathbf{B}\) is the magnetic field, \(p = n k T\) is the kinetic pressure, in which \(n\) is the plasma number density, \(T\) is the kinetic temperature and \(k\) is Boltzmann's constant, and \(\phi\) is the gravitational potential.

In effect, (4) is Euler's equation of motion for a fluid particle of conventional hydrodynamics, modified by the inclusion of the electromagnetic body force term, \(\mathbf{j} \times \mathbf{B}\), which takes account of the interaction between the plasma (conducting fluid) and the magnetic field in the magnetohydrodynamic or hydromagnetic situation now being considered. The equation is linearized in the sense that the convective derivative following the motion of a fluid particle \(\mathbf{u}/\partial t = \mathbf{V} \cdot \nabla \mathbf{V}\), is approximated to the local partial derivative, \(\partial/\partial t\), on the assumption that the differential operator \(\nabla\) acting on \(\mathbf{V}\) does not make a significant quadratic contribution to the whole equation in cases of interest. Further, on the plausible assumption of negligible shearing stresses in the plasma,\(^6,12\) the divergence of the pressure tensor reduces to the simple form shown, namely, \(\nabla p\), where \(p\) is the scalar quantity defined above. Having disposed of these mathematical preliminaries we optimistically assume a steady-state situation, in which the gravitational force contribution is negligible in comparison with the effect of a strong magnetic field acting on the plasma, to obtain the deceptively simple-looking result

\[
\nabla p = \mathbf{j} \times \mathbf{B}, \tag{5}
\]

In fact, this equation, which says that the gradient of the kinetic pressure is balanced by the electromagnetic body force per unit volume, is not particularly easy to solve, as is evident from the following transformation. In electromagnetic units (which are particularly suitable for the equations of plasma physics) the Maxwell equation for the curl of \(\mathbf{B}\) yields, in the steady state,

\[
\mathbf{j} = \frac{1}{4\pi} \text{curl} \mathbf{B}, \tag{6}
\]

so that equation (5) becomes

\[
\nabla p = -\frac{1}{4\pi} (\text{curl} \mathbf{B}) \times \mathbf{B}. \tag{7}
\]

Application of a well-known vector identity for a vector point function, \(a\), namely

\[
\nabla a^2/2 = a \cdot \nabla a + a \times \text{curl} a, \tag{8}
\]

enables equation (7) to be written in the form

\[
\nabla \left( p + \frac{B^2}{8\pi} \right) = -\frac{1}{4\pi} \mathbf{B} \cdot \nabla \mathbf{B}. \tag{9}
\]

It is interesting to observe that the term \(B^2/8\pi\) appears in association with the kinetic pressure, \(p\), and so it can immediately be identified as a magnetic pressure term. On the right-hand side of equation (9), the magnetic field \(\mathbf{B}\) is dotted into the dyadic or second order magnetic field tensor, \(\nabla \mathbf{B}\). So equation (5) has blossomed into a rather formidable looking equation. In fact, a general solution can be obtained by describing the magnetic field in terms of the Frenet-Serret orthogonal curvilinear co-ordinate system which plays a central role in the differential geometry of twisted space curves. But fortunately, for a simple magnetic field, which possesses straight and parallel lines of force, we are able to proceed in a very easy and illuminating manner. Maxwell's equation for the divergence of \(\mathbf{B}\) says that \(\mathbf{B}\) is a solenoidal vector, because, as no free magnetic poles have been discovered in nature, the magnetic field lines close upon themselves. Thus

\[
\text{div} \mathbf{B} = 0, \tag{10}
\]

and hence, using Cartesian co-ordinates, and describing the straight and parallel field by, say

\[
\mathbf{B} = k B_z, \tag{11}
\]

where \(k\) is the unit vector in the \(z\)-direction, we have

\[
\frac{\partial B_z}{\partial z} = 0. \tag{12}
\]

For the chosen magnetic field, equation (9) therefore reduces to

\[
\nabla \left( p + \frac{B^2}{8\pi} \right) = -\frac{1}{4\pi \partial z} = 0, \tag{13}
\]

by equations (11) and (12).

Hence for the simple magnetic field given by equation (11) in which \(\partial B_z/\partial x\) and \(\partial B_z/\partial y\) can be non-zero, i.e., in which the magnetic lines of force may crowd together or thin out in the \(x\) and \(y\) directions, the condition \(\text{div} \mathbf{B} = 0\) ensures the vanishing of the complicated term \(1/4\pi \nabla \mathbf{B} \cdot \nabla \mathbf{B}\) appearing on the right-hand side of equation (9), because the magnetic lines do not crowd together or thin out in the \(z\) direction, as described by equation (12).

The integration of equation (13) is trivial, and we have the result

\[
p + \left( \frac{B^2}{8\pi} \right) = \text{constant}. \tag{14}
\]

The spatial independence of the sum of the kinetic and magnetic pressures here has fundamental consequences in the physics of plasma containment.\(^11\) By idealizing the situation, and assuming that the plasma is perfectly contained by the magnetic field, so that \(p_e\) (the external kinetic pressure beyond the plasma/magnetic field interface) is zero, it follows that the external magnetic field, \(B_0\), is given by

\[
p_e + \left( \frac{B^2}{8\pi} \right) = \left( \frac{B_0^2}{8\pi} \right). \tag{15}
\]

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where the subscript I refers to quantities inside the plasma.

From this equation it is evident that the electrically conducting plasma tends to behave diamagnetically,\(^{21}\) for, clearly, \(B_0\) is less than \(B_1\) for non-zero \(p_1\). Physically, the collective motion of the charged plasma particles produces a magnetic field which tends to reduce the value of \(B_0\) to \(B_1\) within the idealized plasma boundary. If suitably high particle density and mean mass velocity can be attained, the diamagnetic behaviour of the plasma can reduce \(B_1\) to zero. In this limit, in which the charged particles would no longer spiral, but would, rather, move with rectilinear motion, to be reflected at the plasma/magnetic field boundary by the externally applied \(B_0\), we can deduce from equation \((15)\) that the maximum kinetic plasma pressure that can be contained by the external magnetic pressure \(I_{\text{max}} = B_0^2/8\pi\) is given by

\[
\text{(16)}
\]

\[
\text{or, in terms of the plasma temperature, } T, \text{ and the number density, } n,
\]

\[
\text{(17)}
\]

**Ideal Conditions for a Self-sustaining CTR**

Bearing in mind that the particle density of the atmosphere we breathe is in the region of \(10^{22}\), we see that a thermonuclear plasma having \(n = 10^{15}\) starts off at NTP as a very good vacuum. Hence the need for efficient vacuum pumping equipment for a CTR. However, at a temperature of \(10^{6}\) K, the plasma is exerting a kinetic pressure of over one hundred atmospheres! So we conclude that to keep the thermonuclear plasma pressure within reasonable bounds, the plasma must be somewhat tenuous, with a small relative to the atmospheric number density. Even so, \(n\) cannot become too small, because the rate of energy generation per cubic centimetre in a plasma consisting of one species of nuclei is found quite simply to depend on \(n^2\), being given by the expression\(^{22}\)

\[
\text{(18)}
\]

\[
\text{where } \sigma \text{ is the reaction cross section (a measure of the probability of the occurrence of fusion), } v \text{ is the relative velocity of a pair of interacting nuclei, } E \text{ represents the energy released per fusion reaction, and the factor of one half is required to prevent the contribution from any pair of nuclei being counted twice. As a slight generalisation, if two nuclear species are present in the plasma, of type A and type B, say, the product } 4n^2 \text{ in equation (18) must be changed to } n_A n_B, \text{ where } n_A \text{ and } n_B \text{ are the corresponding nuclear number densities. From kinetic theory we recall that the relative velocity } v \text{ will not be constant, but in fact obeys a distribution law: further, the cross section } \sigma \text{ (measured in barns, where one barn is equivalent to } 10^{-24} \text{ square centimetres) depends on particle energy, and so on particle velocity. Equation (18) therefore contains the factor } v, \text{ where the bar over } v \text{ signifies an appropriate average over the velocity distribution, which in cases of interest will be closely a Maxwellian distribution appropriate to the plasma kinetic temperature.}

In a useful device the reaction must be self-sustaining: once the kinetic temperature, \(T\), of the plasma has been raised to a value at which nuclear fusion energy is produced in relative abundance, the power produced in each unit volume of plasma must be great enough to sustain that temperature in the face of unavoidable power loss processes. For example, in the case of an assumed steady-state plasma between electrodes, significant cooling by heat conduction to the electrodes takes place, the coefficient of thermal conductivity of a fully ionized gas somewhat unhelpfully being proportional to \(T^{3/2}\).\(^{21}\) For this plasma configuration it is found theoretically that temperatures much above \(10^6\) K are difficult to achieve.\(^{8}\)

The “loss from the ends” can be simply countered by adopting, say, a circular or doughnut type of configuration, as in ZETA. In a fully ionized plasma, containing completely stripped nuclei, radiation from excitation and recombination processes is fortunately absent. However, one ultimately comes up against a fundamental loss process which cannot be neglected, but which, in fact, results in a serious drain of power from a hot plasma; namely, the so-called bremsstrahlung, or braking radiation. For a tenuous plasma there is no possibility of equilibrium with black-body radiation. Such a plasma is transparent to bremsstrahlung which, viewed classically, occurs due to the acceleration of the highly mobile electrons in the Coulomb field of the relatively massive, and thus relatively slowly moving, positively charged nuclei or ions: the electrons follow curved paths, and so radiate electromagnetic energy in accordance with the formula

\[
\text{(19)}
\]

\[
\text{where } c \text{ is the magnitude of the electron charge, } c \text{ is the light velocity and } \alpha \text{ the particle acceleration. In the quantum-mechanical picture the electrons are descriptively said to be undergoing free-free transition,}\(^{22}\) so radiating. Eventually, following a rather complicated quantum-mechanical derivation, this loss may be written in the form}

\[
\text{(20)}
\]

\[
\text{for a neutral plasma. Here } \gamma_1 \text{ is a constant quantity, } n_i \text{ is the ion number density, } Z \text{ is the atomic number mentioned earlier, and in terms of the electron number density, } n_e, \text{ the macroscopic charge neutrality condition is } n_e = Z n_i. \text{ Clearly, from}
\]
equation (20), the principal radiation loss from a plasma increases rapidly with atomic number. As mentioned earlier, contact of plasma with material walls results in marked de-ionization, and further, impurities sputtered from the walls may, because of their high Z-number, contaminate the plasma and produce significant heat loss due to bremsstrahlung. Absolute purity of a deuterium plasma is therefore required if a practical CTR is to be achieved.

Obviously, if the externally applied magnetic field penetrates the plasma it is attempting to contain, the plasma charged particles will tend to spiral around the lines of magnetic force, and the acceleration producing this helical motion will, by equation (19), result in the production of magnetic bremsstrahlung or cyclotron radiation. A straightforward classical calculation\(^5\) shows that the magnetic bremsstrahlung for a hydrogenic plasma has the form

\[
P_e(\text{magnetic}) = \gamma_e n_e T^2.\tag{21}\]

The \(T^2\) dependence is somewhat alarming until it is realized that the numerical value of \(\gamma_e\) is of order \(\gamma_e/10^7\). Even so, by equating (20) and (21), it is found that the free-free transition and magnetic bremsstrahlung loss contributions are of the same order at a temperature approaching \(10^8\) K, which is in the vicinity of the temperature required for thermonuclear fusion. In fact, to estimate the plasma temperatures required for the nuclear reactions of interest, let it be assumed for simplicity that the confining magnetic field is completely excluded from the plasma, whereupon, since \(P_e\) increases exponentially with temperature, whereas \(P_e\) for free-free transitions varies as the square root of the temperature, we can ideally take the condition \(P_e > P\), to correspond to a self-sustaining CTR, where \(P_e\) and \(P\) are given by equations (18) and (20) respectively, with the proviso that in equation (18) the kinetic energy carried away by the chargeless neutrons, which cannot be held in the magnetic furnace, be neglected. Actually, by equating (18) and (20) we obtain what is called the ideal ignition temperature\(^6\) of a CTR, i.e., the temperature at which the CTR just becomes self-sustaining under the ideal conditions mentioned. As is seen from equations (18) and (20), the ideal ignition temperature is independent of the number density \(n\) of the interacting nuclei, and turns out to be approximately \(4 \times 10^8\) K from the D-D reaction, and about an order of magnitude less for the D-T reaction.

The Problem of Instabilities, and Containment Time Requirements

Unfortunately, the plasma steady state assumed in the derivation of equation (5) has, to date, proved impossible to achieve in practice. Accepting the naive but useful concept that magnetic lines of force behave like stretched rubber bands which repel each other, plasma instability is perhaps best explained in terms of Edward Teller's intuitively based criterion\(^7\). Simply, if the lines of force of the confining field bend towards the plasma, a tendency for interchange of magnetic field lines and plasma exists, and the configuration is unstable. On the other hand, if the magnetic field lines bend away from the plasma, there is no such tendency for interchange to occur. Thus for the famous plasma pinch effect,\(^8,9,11,10,11,12\) in which a current in the region of a million amperes flows through a plasma, so producing a strong azimuthal magnetic field which interacts with the current to produce a magnetic force acting radially inward towards the plasma axis, one would expect intrinsic instability by Teller's criterion. This is indeed found to be the case in practice.

Particular types of instability, such as the sausage and kink instabilities, are, for example, reviewed elsewhere\(^9\) by the present author, who has also, in the same reference, suggested a stability criterion for an assumed steady-state plasma between electrodes, having a boundary surface closely represented by a hyperboloid of revolution of one sheet. Such a plasma boundary surface can be produced by the pinch azimuthal magnetic field in conjunction with the longitudinal guiding magnetic field of a short solenoid centrally located between the electrodes, with its longitudinal axis coincident with the longitudinal axis of the plasma. Application of Teller's criterion to this shape of boundary surface reveals that stabilizing as well as destabilizing forces occur, and hence one can deduce a stability criterion relating the plasma current, the magnetic flux produced by the external solenoid, and the length of the plasma. Experimental verification of this criterion for stability has yet to be achieved, but clearly the concept is of importance. Although, as mentioned, thermonuclear temperatures cannot be achieved by means of this plasma geometry, stabilization in the manner suggested would permit important experimental data to be obtained on basic plasma parameters, such as the electrical, thermal and other transport coefficients.

Although the possibility of steady-state operation of a CTR is of considerable interest and importance, consideration of an assumed ideal pulsed-cycle mode of operation\(^4\) readily provides information on the minimum plasma containment times required for net power production. It offers in principle the possibility of direct conversion\(^5,6,7\) of thermonuclear energy to electrical energy, as will be understood from the concluding remarks. Thus, let a suitably chosen fuel-heating process raise the temperature of the confined plasma in step-function fashion to a thermonuclear value \(T\), above the ideal ignition temperature for the interacting nuclear fuel in use, and let this temperature be maintained for a period of \(\tau\) seconds, after which it is step-func-
tioned back to the initial temperature, $T_i$, assumed negligible in this analysis with respect to $T$. Imagine that neutrons which escape through the confining magnetic field are captured by a suitable moderator within the CTR, so that they are slowed down, with production of heat which can be converted to useful electrical energy via a conventional heat cycle. Imagine also that the bremsstrahlung radiation from the confined plasma, largely as ultraviolet radiation and soft X-rays here, is absorbed elsewhere in the CTR. Then, in terms of $P_x$ and $P_y$, given respectively by equations (18) and (20), the sum of all energy densities, $E$, after $\tau$ seconds is

$$E = \tau(P_x + P_y) + E_{T_1}$$

(22)

where $E_{T_1}$ is the energy density required to heat the fuel to the thermonuclear temperature $T$. For thermal equilibrium of a hydrogenic plasma, we can estimate $E_{T_1}$ from simple kinetic theory as $3kT/2$ (the mean kinetic energy per plasma particle) multiplied by $2n$ (where $2n$ is the total number of plasma particles per cubic centimetre for the hydrogenic case, $Z=1$, $n$ being the number density of the fuel atoms),

$$E_{T_1} \approx 3nkT$$

(23)

where we have neglected the initial temperature $T_i$ with respect to the thermonuclear temperature $T$.

Defining $\eta < 1$ as the efficiency factor for conversion of $E$ to useful CTR output, we must have the inequality

$$\eta E > 3nkT + \tau P$$

(24)

for successful maintenance of the thermonuclear temperature $T$ in the reacting system, i.e., for an overall gain of power.

With the aid of equations (22) and (23), (24) can be rearranged to the form

$$n \tau > 3nkT \left[ \eta P_x - P_y (1-\eta) \right]$$

(25)

and bearing in mind equations (18) and (20), $n \tau$ is evidently independent of $n$ and a function of $T$ only. Using available data, it is found for an assumed efficiency factor of $\eta = \frac{1}{4}$ that the $n \tau$ versus $T$ characteristic exhibits a minimum of about $10^{16}$ for the D-D reaction, and of about $10^{14}$ for the D-T reaction. In each case the temperature at which the minimum $n \tau$ occurs is in excess of the ideal ignition temperature, as obviously required. For the number density of $n = 10^{15}$ fuel particles per cubic centimetre determined earlier, it is evident that a containment time $\tau$ in excess of some ten seconds is required for a deuteron fuel, but greater than $1/10$ seconds for a deuterium-tritium mixture. Even though these times may not seem long intrinsically, the adverse influence of instabilities of the type referred to above makes their achievement so extraordinarily difficult in practice that the technological problem of producing a practical CTR seems virtually insurmountable at present!

**Concluding Remarks**

Returning to an attitude of optimism, a feasible CTR might take the form of a type of magnetic furnace having a containment magnetic field of about $10^5$ gauss in strength, and employing a fuel of deuterium, or perhaps deuterium and tritium, the latter fuel component conceivably being obtained by the lithium blanket breeding process discussed. Realistically, the fuel number density would be closely $n = 10^{15}$ particles per cubic centimetre, and a minimum containment time of several seconds would be required to obtain a power output in excess of that input.

Although the ideal ignition temperature is independent of number density, one notes that a compromise is involved in the choice of $n$. On the one hand the power density $P_x$ given by equation (18) depends on the square of $n$, and so for increased power density, and also for reduced containment time $\tau$, we would like to increase $n$. On the other hand we have seen that for magnetic field containment the value of $n$ is limited by the practical magnetic field strengths attainable by modern techniques, namely about $10^6$ to $10^8$ gauss. In fact, $n = 10^{15}$ particles per cubic centimetre corresponds to a generated power density approaching $10^9$ watts per cubic centimetre, which is about the power density attained in a nuclear fission reactor. For a potential CTR this power density appears to be economically satisfactory, and so we compromise with the choice of $n = 10^{15}$, and grapple with possible methods of keeping the plasma stable for a period in excess of the corresponding minimum containment time. It is worth mentioning in passing that the problem of disposal of radioactive products such as encountered in a fission reactor would not be present in a fusion reactor, although the neutron flux resulting from the fusion process would have to be well shielded, to prevent the materials composing the CTR from becoming radioactive.

In connection with the problem of heating the plasma to thermonuclear temperatures, and to illustrate the complexity of plasma physics calculations, it is important to mention that, in terms of $\mathbf{V}$ and $\mathbf{B}$ introduced in connection with the linearized equation of motion (4), the applied electric field, $E$, and the electron partial pressure $\nabla p_e$, the current density vector is determined by means of a "generalized" Ohm's law

$$\frac{\partial \mathbf{J}}{\partial t} = \mathbf{E} + \frac{\mathbf{V} \times \mathbf{B}}{c} + \frac{e}{en_e} \left( \nabla P_e - \mathbf{j} \times \mathbf{B} \right) - \mathbf{j}/\sigma$$

(26)

where the ratio of electron to ion mass, $m_e/m$, has been neglected in comparison with unity; $n_e$, $c$ and $e$ are as defined earlier, and $\sigma$ is the electrical conductivity, assumed for simplicity to be a tensor of zero order, or, in other words, a scalar quantity. For a fully ionized plasma $\sigma$ is found to vary as $T^{3/2}$, only in the simplest case of a steady-state homogeneous plasma in a zero magnetic field.
familiar vector point function form of Ohm's law,
\[ j = \sigma E, \]
recovered from equation (26). By use of equation (27), it is seen that \( jE \), the rate at which the electric field \( E \) does work on the current \( j \), per unit volume of the plasma, is equal to the irreversible Joule heating term, \( j^2/\sigma \), and hence, remembering the \( T^{\gamma/2} \) temperature dependence of \( \sigma \), it follows that the Joule heating becomes less effective\(^2\) when the temperature increases. Coupled with the tendency of the plasma electrons to "run away" from the system,\(^1\) a limit in the region of \( 10^{9} K \) is imposed on this form of plasma heating. Bearing in mind that the requirements for effective Joule heating are contrary to those for effective, stable containment,\(^1\) one has to explore other heating possibilities, such as magnetic pumping\(^2\) of the plasma. In this process, the plasma charged particles are put through a compression-expansion cycle by means of a time-periodic externally applied magnetic field, with period suitably related to certain characteristic times of the plasma positive ions. Thermodynamic considerations show this process to be irreversible, with consequent increase of the plasma temperature. The analysis here is complicated, and adds to the general challenge offered by this particular possibility for the production of power.

In the general spirit of optimism referred to at the commencement of these concluding remarks, and with reference to the previous section, speculation on the possibility of efficient direct conversion of the thermal energy of the confined plasma charged particles to electrical energy has taken place in various parts of the world. To understand the basic mechanism here, we assume the plasma—a highly conducting electrical field at thermonuclear temperatures—to be ideally contained by its confining magnetic field, under conditions where equation (16) applies, i.e., \( n kT_{\text{max}} = B_0^2 / 8 \pi \). Now imagine that we increase \( B_0 \) by a small amount. Then initially the plasma number density \( n \) will increase, and so from equation (18) the generated power density, being proportional to \( n^2 \), will increase too. In this time-dependent situation, the plasma temperature will therefore also increase, and the increasing kinetic pressure, proportional to the product of \( n \) and \( T \), will cause the plasma to expand against the magnetic pressure of the confining field. In effect, the expanding plasma does work on the confining magnetic field, which may perhaps be likened to a magnetic piston.\(^5\) The time-dependent changes in the confining magnetic field strength produced by this process would permit an e.m.f. to be induced in a suitably arranged conducting circuit external to the reacting plasma nuclei, and so in principle the kinetic energy of the charged reaction products could be converted directly to electrical energy in an external conducting circuit. A similar expansion of plasma against external magnetic field would be found in the pulsed-cycle mode of CTR operation, which should therefore lend itself to direct conversion, as mentioned earlier. Obviously, from what has been said above, much theoretical and experimental research in the field of plasma physics has yet to be successfully completed before the practical realizability of direct conversion can be checked.

In common with other fields of scientific endeavour, measurements in the plasma field are of considerable importance. Plasma diagnostic techniques\(^1\) are primarily concerned with making measurements of basic plasma parameters in such a manner that the highly ionized gas is not appreciably disturbed by the chosen measuring process. Here a deep insight into the basic properties of a plasma is of vital importance in the development of satisfactory measuring techniques. While the plasma oscillations mentioned in the introduction may, on the one hand, have an adverse influence on plasma stability, on the other hand the existence of an electron plasma oscillation frequency, above which electromagnetic waves may be propagated through the plasma, and below which they are attenuated, so that the plasma as a transmission medium behaves somewhat like a high-pass filter, leads to a practical method for estimating the number density, \( n \). A simple calculation shows that the required microwave transmission frequency here lies in the millimeter wavelength part of the electromagnetic spectrum.

Altogether, plasma physics is a fascinating subject in its own right, combining principles of conventional hydrodynamics and classical electrodynamics, and having an ultimate application goal of immense importance to civilization—the production of thermonuclear power from the controlled fusion of the light nuclei. Since it has been estimated that the surface waters of the earth contain some \( 10^{14} \) tons of deuterium, which can be extracted from enriched water by a relatively inexpensive electrolysis process, the remark that solution of the CTR problem would solve our power problems for millions of years to come is no exaggeration.

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References

The following selection of references, which have been mentioned in particular contexts above, contain interesting information on the topic of this paper, and have been generally helpful in its preparation:

Letter to the Editor

Science and Government Policy

Sir,—At recent meetings of the Academy of Science, concern was expressed at the position of science in relation to Government policy. The council of the Academy (Canberra Times, 30.4.66) is reported as being ‘disappointed that no action has been taken to establish the proposed Government machinery for advice on national scientific matters’.

The Governor-General, Lord Casey, addressed the annual dinner of the Academy and is reported as saying (Canberra Times, 30.4.66) that ‘the more important thing is to make it easier for the higher echelons of Government, both Parliamentarians and the civil service, to understand what it is all about’.

I, too, am concerned at the lack of scientific knowledge at these levels, but I believe that they form part of a much greater problem — the lack of people with scientific training at all levels of the Public Service, Parliament, and in the administrative structures of business. Furthermore, I think it is a matter with which the Institute could properly concern itself.

There is an increasing tendency for the policy divisions of all Commonwealth Departments to be staffed by economists and there has long been a disproportionate number of lawyers in Parliament. Some of these no doubt are necessary, but I do not think that economists and lawyers can claim to be ideally trained for decision-making and administration in the world of today. I think it is dangerous that so much should be left in the hands of so few, and nowhere is the need for a broadening of the background of the policymakers greater than in the field of science.

It is necessary not to demand special favours, but to remove the active discrimination against scientists in the Public Service. A recent example is an advertisement for careers in the Australian Diplomatic Service. The qualifications are a ‘University degree preferably in Arts, Economics, or Law. Honours standard preferred’. The record of scientific international relations is so immeasurably superior to relations on the political level that scientists can reasonably claim a place in the list of preferred degrees.

But more important are the positions in the higher echelons of departments such as Treasury, Trade, and National Development. Scientists are doubly handicapped; firstly, we are to some extent hoist by our own petard in that we are paid a salary such that any position in a policy Secretariat to which we may reasonably aspire is at a fairly high level and the inevitable reaction of the selectors is ‘But you have had no experience in this type of work’. There is thus an inbuilt preference for some person who possibly started his career as a public servant as a base grade clerk, acquired some mediocre qualification in economics or political science (1) on the way up, and has had a few years’ experience on the bottom rungs of the policy-making hierarchy. Secondly, there is a frequently stated preference for degrees in economics.

Now I believe that policy making is not such an esoteric art as the practitioners try to make out, and that a decision based on a scientific assessment of the information available is more likely to be correct. It follows that scientific training is a useful thing to have in these positions, not to the exclusion of all economists, etc., but in a partnership, which would be a vast improvement on the use of economists to the exclusion of scientists.

An editorial in Nature (209, 1272, 26th March, 1966) refers to a survey conducted by the American Institute of Physics which, inter alia, compares salaries paid to scientists and managers. Some of the editorial comment is relevant here: ‘The profession of physics has something in common with professional football, where a man must reckon that his earning power will disappear altogether by forty. This suggests that university departments might deliberately set out to provide their students with means of moving out of research into administration half-way through an industrial career, possibly by coupling academic instruction with more deliberate training in the techniques of management and administration’. In Australia, I do not think the relative salaries of scientists and managers are disadvantageous to scientists, but obstacles to the scientist of forty who wishes to switch to administration are too great.

It is probably unrealistic to expect that Universities teach undergraduates the techniques of management and administration, but it is too much to hope for suitable courses for scientists in mid-
career? Whether these are given in Universities, or institutions such as the Administrative Staff College, does not much matter, but I feel it is important that more of such courses be given, and at a lower level than at Mt. Eliza. I would propose most urgently that the Institute make some move in this direction.

Were more scientists to be introduced in what is termed, I believe, 'middle management', the difficulties mentioned by the Academy and Lord Casey would be very much reduced, the country would be better governed, and some middle-aged scientists would be happier.—Peter M. Stott.

7 Longstaff Street,
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Notes and News

Simulation Symposium

The Statistical Society of Australia (N.S.W. Branch) is holding a Symposium on the subject 'Simulation' at the University of New South Wales from Wednesday to Friday, August 24-26, 1966. There are seventeen papers on topics covering economics, industrial, management and scientific applications of these techniques. For further information, members are advised to contact Mr. R. T. Leslie, Assistant Secretary, Statistical Society of Australia, 7th Floor, Alpha House, 60 King Street, Newtown, N.S.W.

Education Group (South Australian Branch)

The meeting, held at Henley Beach High School on 9th March, began with a display of physics apparatus typical of that being supplied to High Schools by the South Australian Education Department. Most of the apparatus on display was suitable for demonstrations at Leaving and Matriculation level.

The Chairman of the Education Group, Mr. C. G. Wilson, introduced the speaker, Mr. D. A. S. Maynard. After a distinguished career as a teacher of mathematics and Physics, and as a Head Master, Mr. Maynard was recently appointed as Inspector of High Schools in the South Australian Education Department. He is Convenor of the Physics Curriculum Committee of the High Schools Branch and is responsible for advising the Superintendent of High Schools on how Commonwealth Aid money should be spent. Mr. Maynard's topic for the evening was "Commonwealth Aid and High School Physics Apparatus". A resume of his talk is given below.

The first Commonwealth Aid grant for Science teaching was made in 1964. This grant of £5 million was divided between State, Independent and Church schools, and was to be used for the provision of Science equipment and buildings. The share of this grant received by the South Australian Education Department, Secondary Schools for Science equipment was £150,000 to be divided between the three types of secondary schools in South Australia, viz., Area, Technical High and High Schools, and the different branches of science. The same allocation was made in 1965 and it is hoped that a similar amount will be made available in 1966.

in choosing apparatus for supply to the High Schools, the following aims have been kept in mind.

1. Practical Work.
   a. The attempt has been made to find apparatus of simple design and robust construction, which is cheap enough to be supplied in quantity. The aim is to develop towards a P.S.S.C. type of practical work, wherein the child learns through his own experiments, without the wholesale adoption of the P.S.S.C. course and apparatus. Mr. Maynard showed a simple optical kit of local design and manufacture, and a Soviet designed apparatus to illustrate the laws of conservation of momentum and energy.

   b. More complex apparatus required for Matriculation Physics is to be supplied on a more liberal basis so that the time for a cycle of practical experiment can be reduced to a minimum. This reduction of time is clearly desirable if theory and practical work are to go hand in hand, and are to reinforce one another in the minds of students.

   c. New experiments are being introduced to broaden the scope of practical work, e.g., experiments on radioactivity, Millikan's experiment.

2. Demonstration Work.

   Many items of demonstration apparatus, e.g., Van de Graaff generator, electrosopes, vacuum apparatus, large scale electric meters, audio oscillators, cathode ray oscilloscopes, not previously available to High Schools have already been supplied to the larger schools. In course of time, all schools will have such a range of demonstration apparatus that it rarely will be necessary to talk about apparatus without, at the same time, demonstrating it.

When a piece of apparatus is under consideration for use in High Schools, samples are placed in selected schools where they are used for a trial period. The teachers concerned then report on their effectiveness and suitability.

In-service conferences are held regularly to guide and train teachers in the use of the new apparatus. These have proved useful for the sharing of ideas, and have had a lively and stimulating effect on the teaching of physics throughout the State.

Mr. Maynard concluded his remarks by commenting on the lack of trained teachers. The
shortage is particularly marked among graduates in physics. In 1965, of the 3rd year Science units being taken by students of the Adelaide Teachers' College, less than 4 per cent. were physics. This shortage of qualified teachers is acting as a brake on the quality of physics teaching, just when the apparatus situation is improving so dramatically.

An interesting question and answer session followed. Finally, 3 cm. wave apparatus constructed at the South Australian Instute of Technology was demonstrated to the gathering.

Informal Meeting on Laser Research
The second meeting of an informal group engaged on laser research was held at D.S.I. on 23rd and 24th May. These meetings were instituted between Monash University, Weapons Research Establishment and Defence Standards Laboratories, to exchange news of progress, to pool techniques, and to arrange co-operative programmes of work.

W.R.E. is concerned with communication aspects. Mr. J. Pyle described modulation experiments, including preparation of KDP crystals and crystal geometry for coupled modulation techniques. Mr. Wenk reported on the frequency stabilisation of lasers. Mr. B. See gave constructional details of a CO₂ laser. Dr. Hughes discussed the CW Argon laser and problems of a high pulse rate, high energy optical radar; he reported on W.R.E. grown CaWO₄ and a proposal to grow YAG crystals.

Mr. G. Troup of Monash spoke on theoretical aspects of time domain analysis of photon beams, and Mr. P. Pearl described an experimental programme in this field. Dr. H. Moray reported on theoretical aspects of stimulated processes. Other Monash workers reported on solid state aspects; Mr. B. Tobin spoke on dispersion harmonics in barium titanate and Dr. R. Chamberlain spoke on energy loss mechanisms in the fluorescence process; Mr. Z. Padanyi discussed photon-magnon interactions.

Results of D.S.I. work on passive Q switching with Al-phthalocyanine were given by Dr. Bowe, and Mr. W. Gibbs reported on beam structure and formation time using active Q switching. Mr. Whittle discussed experimental and theoretical aspects of pumping cavity design. Dr. Tregellas-Williams relayed information gathered at a recent International meeting.

This informal type of meeting has proved valuable, and a third meeting will be held in November-December, 1966. Workers in the field of laser research who feel they would like to contribute are invited to get in touch with me at D.S.I.—JOHN L. FARRANDS.

A.A.E.C. Research Establishment Open Days

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