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**Report on the Solar Physics—Plasma Physics  
Workshop Held at Stanford University,  
September 17-20, 1974**

by

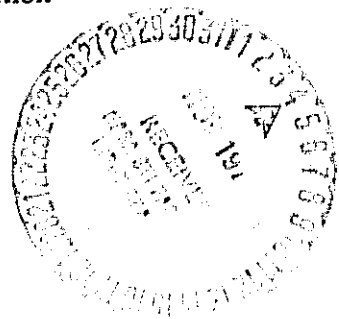
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**October 1974**

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HELD AT STANFORD UNIVERSITY, SEPTEMBER 17-20, 1974

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## ABSTRACT

This report summarizes the proceedings of a meeting held on September 17 - 20, 1974, at Stanford University. The purpose was to explore plasma physics problems which arise in the study of solar physics. Sessions were concerned with specific questions including the following: Is the solar plasma thermal or non-thermal? What spectroscopic data is required? What types of magnetic field structures exist? Do MHD instabilities occur? Do resistive or non-MHD instabilities occur? What mechanisms of particle acceleration have been proposed? What information do we have concerning shock waves? Very few questions were answered categorically but, for each question, there was discussion concerning the observational evidence, theoretical analyses, and existing or potential laboratory and numerical experiments.

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SOLAR PHYSICS - PLASMA PHYSICS WORKSHOP  
STANFORD UNIVERSITY  
September 17-20, 1974

Session 1.

1. Does simulation of the solar plasma require the production of non-thermal plasmas?
2. If so, with what characteristics?
3. Is simulation best achieved with laboratory or computer experiments?

Speakers: Baum, Cowan, Sturrock and Walker

Scientific Secretary: J.M. Beckers

The first question can be reworded: "Are there non-thermal plasmas on the sun?" The answer, of course, has to be "yes". Specifically discussed were solar flares by Baum and the solar wind near the planets Earth and Mercury by Cowan.

Baum discussed a simulation of the solar flare plasma in the laboratory in an experiment using two parallel rods 10 cm. apart through which he sends two sudden, parallel currents. The resulting mass motions and magnetic field changes are studied and then scaled to solar conditions. Scaling and the study of laboratory gases at densities existing in the sun, especially the corona, is always a major problem.

Cowan described Los Alamos measurements of actual electron velocity distributions in the solar wind. These are not purely Maxwellian. In fact the measurements can be represented very well by fully mixed so called hot ( $\sim 7 \times 10^5$  °K) and cold ( $\sim 1 \times 10^5$  °K) components. In addition to this so-called bimaxwellian non-thermal velocity distribution for velocities along the field lines, there is a different bimaxwellian distribution for velocities at right angles

to the field lines. Collisionless plasmas such as the solar wind are very likely to be non-thermal. Solar flares are not a collisionless plasma. Non-thermal behavior there is very short-lived. In Baum and Bratenahl's experiment there is also a short-lived ( $\sim 1 \mu$  sec) non-thermal phase characterized by runaway electrons and x-ray radiation.

The experiment of Baum and Bratenahl specifically studies the process of magnetic field line reconnection. They observe a quiescent reconnection phase during which magnetic flux and energy are stored. A transition to anomalous conductivity triggers the release of this stored energy in an "impulsive flux transfer event" during which magnetic flux is transferred across the separatrix. By Faraday's law, this flux change accompanies an electric field along the neutral line which is measured to be 3 kV. The energy dissipated in the non-thermal event is estimated to be  $10^8$  ergs. According to Baum and Bratenahl, these laboratory parameters translate to solar equivalents of  $10^{30}$  ergs released in  $10^2$  seconds generating an electric potential of  $10^{10}$  volts.

Baum suggested a new experiment to be performed with two solenoids which would closely simulate the interaction of two bipolar sunspot groups. No computer simulations were proposed.

The second question was not really answered. One wishes to simulate the solar plasma as closely as possible, but the solar plasmas have densities varying from  $10^{14}$  to  $10^0$  electrons per  $\text{cm}^3$ , temperatures from  $10^4$  to  $10^7$  °K, magnetic fields from 3000 to  $10^{-3}$  gauss and scales of  $10^5$  km downwards. These parameters can not all be attained (or even scaled) in the laboratory, suggesting that one pursue computer experiments which might permit one to extrapolate results from laboratory

conditions to solar conditions.

Other questions arose to which no satisfactory answer was given: "What effects do non-thermal (nonmaxwellian) velocity distributions of, for instance, electrons have on the calculations of spectroscopic parameters?" (Rosenberg); "Are we really justified in assigning a unique temperature to a spectral line, as is now often done for EUV lines, if we have a non-thermal plasma?" (Rosenberg); and "Does a non-thermal velocity distribution permit us to understand the simultaneous emission of lines of low temperature ( $10^4$  °K) and high temperature ( $10^7$  °K) in active region loops?" (Brueckner).

Session 2.

1. How can we best obtain the spectroscopic data we need to interpret solar observations?
2. Do we need new calculations, new laboratory experiments, or new calibration techniques?

Speakers: Datla, Hummer and Walker

Scientific Secretary: J.M. Beckers

Hummer discussed the theoretical approach to obtaining the spectroscopic data, and Walker and Datla discussed the experimental methods with reference to the sun and the theta pinch, respectively.

Hummer stated that JILA now has a set of computer codes available for calculation of atomic parameters, including some that include relativistic effects. These codes permit the determination of  $f$ -values and cross sections for highly complex configurations. Results compare well with the results of beam-foil experiments, thus creating a high degree of confidence in the theoretical results. Experimental determinations of the atomic parameters are crucial for the verification of the theoretical results. Theory has now reached a level where one can expect rather accurate results (at least within a factor of 2). Theoretical results are essential for those temperature-density situations where laboratory results are unattainable.

Walker discussed an interpretation of the solar spectrum between 7 and 25 Å. Abundances agree with photospheric values, and emission-measure versus temperature curves are consistent. Some of the solar-derived atomic cross sections may actually be better than the theoretical ones. Coronal line intensity ratios for the hydrogenic ions O VIII, Mg XII and Si XIV, and for the neon-like ion Fe XVII were found to be



in good agreement with theory. The Fe XVII observations have been used to derive excitation rates for the  $2s^2 2p^6 1S - 2s 2p^6 3d^3 L$  excitations, for which no theoretical rate coefficients are available.

Data discussed collisional rate coefficients of excitation and ionization for the Fe VIII, Fe IX and Fe X ions derived from the Maryland theta-pinch experiments. Comparison of the relative rates of excitation with theoretical calculations based on the Coulomb-Born approximation showed disagreements as high as 5 ~ 6 orders of magnitude in some transitions. However, the experiment was in agreement with solar observations. With the new codes available at JILA, theoretical values for these highly charged systems should be accurate to  $\approx 30\%$ . The experimental ionization rates for these ions are about 50% smaller than the theoretical estimates, as was found for Li, Be and Na sequences in previous Maryland theta-pinch experiments, suggesting a need to improve the theory of ionization.

In answer to the second question, the need was expressed for (a) an extended bibliography of atomic data (one is to be published by JILA in April, 1975), (b) more accurate data for spin-forbidden coronal lines (Brueckner). Laboratory experiments for these lines are virtually impossible because of the long lifetimes involved, so theoretical determinations are essential.

### Session 3.

1. What types of magnetic field structures seem to exist in the solar atmosphere? Can they be understood?
2. Are there procedures for determining the field configuration in the atmosphere from available observational data and, if so, how reliable are they?
3. Can the magnetic field structures be studied in the laboratory or by computer experiments?

Speakers: Beckers, Brattonahl, Jockers, Kundu, Rust, Vorpahl and Vrabec

Scientific Secretary: Hans Rosenberg

Most of the session's time was devoted to questions (1) and (2), and little to (3).

#### Question 1.

a) The only dependable magnetic-field determinations are attained from the Zeeman splitting of spectral lines. Thus the component of  $\vec{B}$  parallel to the line of sight is obtained with varying spatial and time resolution at various heights in the photosphere and chromosphere. Increased spatial resolution yields higher field strengths and more bunched fields: in the quiet photosphere, the field aggregates in regions of  $\approx 1000 - 1500$  G; in spots  $B_{\parallel} \sim 3000$  G (apparently not bunched); in neutral flashes  $B_{\parallel} \sim 5500$  G, within a spot for which the average field strength is  $\sim 2200$  G (Beckers). The flash is not a wave, but problems arise with the confinement of such a strong field (Meyer). Evolution of high-resolution magnetograms shows inflow of flux in the form of pores into growing sunspots (Vrabec). A decaying spot is typically situated in the center of a special supergranular cell with flux moving away from the spot towards the cell boundary.

b) The stokes polarimeter should yield important information about

$\vec{B}$  with high time and spatial resolution, although  $B_{\perp}$  will be less accurately determined than  $B_{\parallel}$ .

c) Coronal magnetic field strengths obtained by radio methods are highly untrustworthy (Kundu). He suggested an estimate of 300 - 500 G above active regions as determined from polarization data of microwave emission.

d) Most of the knowledge of field structure is derived from the morphology of fine structures in various spectral bands (optical, EUV, x-rays, radio) assuming that the emission outlines the magnetic field structure: --

H $\alpha$  observations: Fibril structures in the chromosphere, spiralling structures around sunspots, filaments overlying neutral lines, twisting and untwisting in flaring regions and erupting prominences, and coronal rain outlining coronal field structures.

X-ray observations (Vorpahl): These show coronal loops, and possibly arcades. Some loops connect well-separated active regions, even crossing the equator, similar to connections implied by sympathetic radio bursts (Culgoora, Kundu). The emergence of new flux in the photosphere is followed within a few hours by significant soft  $\gamma$ -ray radiation in the corona; when the photospheric field decreases or polarities separate, the initially intense x-ray structures become diffuse and lose their sharp definition within hours. Non-catastrophic field reconnection seems to occur between older active regions and new ones that appear and develop nearby. A more energetic case of field reconnection, with a subsequent release of energy, may have been observed when some limb loops appeared to coalesce and brighten on 13 - 14 August, 1973. Lasting

for 24 hours, the event emitted ten times more x-rays than the entire sun at maximum.

Radio observations: Type III electrons reaching the earth, and possibly moving Type IV bursts, indicate the existence of open field lines.

Questions which remained are: Why do some morphological structures appear dark and others light, whether in H  $\alpha$  or in x-rays? Why do some field lines connect distant foot-points and others not? What is the cause of apparent twisting?

#### Question 2.

Models of the field structure are constructed using magnetograms; they are then compared with the morphology described in (1d). The assumptions for the models vary:

- a) current free model:  $\nabla \times \vec{B} = 0$ ,  $B_{\parallel}$  given in the photosphere.
- b) force-free (FF) model:  $\nabla \times \vec{B} = \alpha \vec{B}$ ,  $\alpha$  chosen and constant,  $B_{\parallel}$  given (Nakagawa et al.).
- c) force-free model,  $\alpha$  not constant but more specific boundary conditions assumed on  $\vec{B}$  (Barnes, Sturrock, see also Session 4).
- d) "born-free" approximation:  $\nabla \cdot \vec{B} = 0$ ,  $B_{\parallel}$  given in the photosphere, a good guess from the morphology, and some insight in the topology.

Jockers showed that an isolated region of one polarity inside a region of opposite polarity implies the existence of a neutral point somewhere above in the atmosphere.

The models try to give a complete specification of the field structure in the hope of finding out what forces are present and what energies are available for flares. Many difficulties were pointed out:

--there is (as yet) no physical argument as to how to choose  $\alpha$ , or how

constant  $\alpha$  should be (except for its constancy along a field line).

--there is a great ambiguity in picking the computed field line which is to be compared with the morphological structures (Excitement in the audience!).

--at great heights the predicted structure is very uncertain.

--departures from force-free fields, such as neutral sheets, do not show up in the models (Sturrock).

--even though the comparison may look satisfying, small departures from potential or force-free structures can contain large currents and large amounts of surplus energy (Bratenahl, Rosenberg).

It was agreed that force-free or nearly force-free configurations should be common except during transient events, but that it is difficult to prove by comparison of morphology with the models.

### Question 3.

Bratenahl suggested that a quasi-force-free situation should be considered, basing this on laboratory experiments. In quasi-force-free situations, currents flow in regions where  $B = 0$ , and along the separatrix between magnetic structures. There is mass flow and, although it is not locally force-free, it is force-free over the scale of the whole structure. Field annihilation seems to occur in x-type neutral points rather than in neutral sheets.

Whether the magnetic structures could be studied on the computer was not really answered (See also Session 4). For a realistic situation it seems necessary to include both three dimensions and time evolution.

#### Session 4.

1. Does the evidence indicate that MHD instabilities are involved in some solar phenomena such as spicules, surges or erupting prominences?
2. If so, can one examine some of these phenomena by laboratory or computer experiments?

Speakers: Barnes, Brueckner, Tandberg-Hanssen and Zirin

Scientific Secretary: E.R. Priest

The overwhelming answer to the first question was yes. After cataloging the main instabilities, Tandberg-Hanssen described the properties of solar prominences. A quiescent prominence is a huge vertical sheet of plasma, stable for many weeks but then subject to a "disparition brusque" phase in which the whole structure rises within a few hours and escapes from the sun, often displaying helical structure in the process. (The time scale may be as short as 5 minutes for the smallest prominences -- Moore). One result is sometimes an in-fall of material, producing a chromospheric brightening which Zirin feels should not be called a flare. Active region prominences are of many types. For instance, a surge ascends at about 100 km/s to about 30,000 km and descends along a similar, though not necessarily identical, path (Rust). Sprays are more violent with such large speeds (1000 km/s) that they escape.

The following are some examples of proposed prominence instabilities. Nakagawa and Malville suggest that the Rayleigh-Taylor instability can explain the observation that long high-latitude prominences tend to break up into regularly spaced parts. Zirin feels that a prominence is by nature buoyant so that the problem is to hold it down rather than

support it; he was supported by Woodbury and Sturrock's model in which the prominence sits in a helical field closed above by a field which, when removed, allows the prominence to erupt. Kuperus and Tandberg-Hanssen suggest that quiescent prominences form with the aid of a tearing-mode instability in the current sheet which results after a closed structure has been blown open by a pressure build-up. Finally, it is possible that pinch instabilities are relevant: perhaps a surge is a stabilized pinch, whereas the blobs in a spray may come from a sausage-type instability and the twists in coronal rain may be due to a helical instability. During the discussion it was mentioned that helical structure does not necessarily imply a kink instability (Rosenberg) and may be apparent rather than real, as in the wavy-curtain auroral structure (Bratenahl).

Brueckner described the problem of the energy balance of the quiet transition region. He suggested that the region may not be quiet at all and should be characterized by many temperatures. He further suggested that the relevant coefficient of thermal conductivity is determined by turbulence, and that MHD instabilities heat the corona. (However, Meyer and Zirin were not too willing to abandon the usual heating model.) He presented some fascinating observations which suggest the following: UV emission is concentrated in spicule bushes around which there are 30 km/s non-thermal motions; spicules are much taller over polar regions; coronal holes do not penetrate to the transition region; a prominence shows up progressively in higher temperature lines as it erupts.

Barnes described some calculations of the storage of magnetic energy

in a force-free field which is gradually twisted. The magnetic field lines are seen to expand and eventually their energy exceeds that of the corresponding open field configuration. It is not clear how a transfer to the lower energy state occurs (Moore) nor whether an Eulerian description of the system is appropriate (Jockers).

Zirin gave some comments about flares. Typically, new flux emerges and extends the "neutral" line until a flare occurs. Alternatively, the flare may take place after the appearance of a fibril crossing. Twisting motion is common and 5-second flashes are observed in the upper photosphere. Also the flash and explosive phases are quite distinct in high-energy flares.

In reply to the second question, Tandberg-Hanssen called attention to the pinch (Karr) and reconnection (Bratenahl and Baum) experiments and commented that many computational experiments have been performed with a laboratory situation rather than the sun in mind.



Session 5.

1. Does the evidence indicate that energy released in solar flares is due to finite resistivity or non-MHD instabilities? If so, can one or more of these possible instabilities be examined experimentally?

Speakers: Baum, Bratenahi, Brueckner, Buneman, Kane, Lin and Van Hoven

Scientific Secretary: D.G. Wentzel

Theories concerning magnetic-field reconnection using Ohmic resistivity are marginally encouraging. Van Hoven summarized two of the reasonably popular theoretical models. "Something like Pet chek's solution, as modified over the years, has stood the test of time", although it is a steady-state solution that says nothing about the origin of a flare and requires an inconsistently minute region of field reconnection. The tearing instability is a second favorite. Van Hoven summarized attempts to compute the development of this linear instability until it saturates. The rates of flow and reconnection at saturation are of the order of those involved in Petschek's solution, so that the two may be related. The outcome is a dissipation time scale that is intermediate between the purely dynamic and purely resistive time scales, and observational values can be obtained for widths of the neutral sheet of 10 to 100 km. Since such structures are observed down to the smallest observable scales of 1000 km, the required values appear plausible. The two dissipation models may also be related in that the tearing mode may operate at the central region of a larger volume satisfying Petschek's model. Thus one discusses two-stage magnetic dissipation.

Experiments in which the current is driven along the neutral sheet tend to show the tearing instability, whereas that of Baum and Bratenahl generates only one x-type neutral point where anomalous resistivity develops. The difference might be due to the different initial current but is more likely due to the different source geometry of the latter experiment. The experiments and the nonlinear tearing computation apply only to magnetic Reynolds numbers much smaller than on the Sun. The theoretical solutions may apply to field reconnections that proceed quite commonly on the Sun, but perhaps not to flares. If the solar resistivity is locally anomalous, it probably becomes so suddenly. Baum and Bratenahl simulated such a "turning-on" in their experiment using an equivalent circuit and indeed found an essentially explosive behavior. They examined two cases where the neutral line resistance was constant ("quiescent phase") and where the resistance increased exponentially in time ("impulsive phase"). They identify the quiescent phase with the Petschek mode which now becomes the preflare state. The impulsive phase is identified with the flare itself. However, Moore argued that x-ray data at flare maximum are consistent with the notion that flare cooling is balanced by heating associated with a steady field merging controlled by the Alfvén speed.

Baum and Bratenahl also discussed the potential field of two bipolar sunspot regions showing how magnetic energy could be stored and impulsively released in a configuration topologically quite similar to their laboratory experiment. Bratenahl stressed that the reconnection rate should be measured by the electric field ( $E \approx \frac{V}{c} B$ ) rather than by the Alfvén Mach number ( $M \sim V/V_A$ ) as is commonly done.

The very intense and highly localized onset of a flare was demonstrated by Brueckner using Skylab observations. Brueckner discussed a kernel of diameter 3000 km, lying above a magnetic neutral line, observed in the Fe XXIV line representing  $T \approx 25 \times 10^6$  K. He argued by comparison to other data that this region was heated in 10 seconds, or at most 100 seconds, and that it was the cause of most other aspects of the flare, including the violent disruption of structures observed at about  $2 \times 10^6$  K. This compactness tends to support the theoretical requirement that magnetic fields are dissipated only in small regions.

Spicer summarized a few theoretical possibilities of releasing energy at the top of a magnetic loop, depending on either classical or collisionless resistivity. His talk elicited discussion between Skylab and optical observers on the identity (height, gas density, stability) of loops that are observed to lead to flares. Apparently, the theoretical cause of a flare (if unique) is still not identified.

Kane and Lin showed for a variety of flares that the energy residing in non-thermal electrons is adequate to account for all other observed radiation processes in many (though not all) flares. If non-thermal electrons are the prime product of the flare energy release, then the phenomenon must be collisionless. Buneman reminded the audience that tearing mode instability also exists in a collisionless form.

Session 6.

1. What suggestions have been made concerning particle acceleration in solar flares?
2. Can some of these suggestions be checked experimentally?

Speakers: Frost, Kane, Liebenberg, Lin, Sakurai and Smith

Scientific Secretary: P.J. Baum

A variety of suggestions were offered for particle acceleration mechanisms, although none met universal approval, and several experimental suggestions were offered.

Smith cited acceleration models by Alfvén and Carlquist, Syrovatskii, Takakura, Friedman, and Smith. Smith criticized Alfvén's model on two grounds: (i) The L/R time constant is much larger than  $10^2$  seconds for the parameters he chooses; and (ii) The force-free filament is kink-unstable anyway. The audience was referred to Anzer's paper in Solar Physics for criticism of Syrovatskii's model. Takakura's model was regarded as unnecessarily complicated, and Friedman's model was criticized on the grounds that the particles were accelerated isotropically by plasma waves, whereas observation indicates an isotropic acceleration.

Smith's model attempts to produce mildly relativistic electrons with a power-law energy spectrum. The spectral index should be 2.3 to 4.6. In this model electrons are accelerated from 0.01 keV up to 115.0 keV by Fermi acceleration. The particles then generate plasma waves which act as a filter to produce the required spectral index. He specifically described an x-type neutral point model in which a select group of particles in the diffusion region are Fermi accelerated by "collisions" with field lines. Kulsrud asked why the energized particles

were not decelerated by the field lines farther from the diffusion region, and Rosenberg and Michel expressed reservations about the philosophy of the model.

Smith mentioned the laboratory experiment of Baum and Bratenahl where scale limitations reduce the electron flux from the desired level and which generates ion-acoustic rather than Langmuir waves. He mentioned also the beautiful prediction by Baranger and Mozer that plasma turbulence would produce satellite spectral lines around forbidden helium lines. These satellites have been observed in laboratory experiments and their spacing and intensity give information on the level of turbulence in the plasma. This was suggested as a solar experiment although the low density required may make it impractical.

Shock heating also was proposed as an acceleration mechanism although Smith felt that it would be difficult to keep the particles in resonance with the shocks. He felt that Sonnerup's model is inadequate.

Frost presented OSO-5 observational data on a number of flare-related x-ray events typically in the range 28-55 keV. He finds two components to the x-ray signal, one fast and one slow. These two x-ray signatures are believed to represent two acceleration mechanisms, thereby explaining the break at 100 keV in the spectral-index curve. He discussed the correlation between microwave bursts (B field dependent) and x-ray bursts (density dependent). It is still questionable whether the acceleration mechanisms are short-lived or continuous.

Kane suggested that electrons are accelerated near the base of field structures resembling Sturrock's Y-type neutral point model. He considers the acceleration mechanism to be either continuous or repetitive with a

period of about one second. The spectral index is inferred to be 3 - 4. The electron acceleration region should be located where the electron density is  $10^9 \text{ cm}^{-3}$  or less.

Lin also suggested two different types of acceleration mechanisms in flares. He discussed the relative release times of electrons and protons, with protons generally being accelerated later than electrons. He proposed that only 1% of electrons escape the flare region while 99% of the protons escape. He showed an event from August, 1972, during which four different particle injections took place followed by four interplanetary shocks. He suggested that the second acceleration phase is caused by shock waves near coronal height.

Sakurai presented observational evidence that elements with high atomic numbers (iron for example) frequently are up to ten times more abundant in solar cosmic rays than in the solar atmosphere. This phenomenon seems to be energy-dependent.

Liebenberg studied a white-light streamer above an active region with a Fabry-Perot interferometer, and line profiles were presented. The streamer seemed to behave much like other coronal features although it was slightly twisted.

## Session 7.

1. What evidence do we have concerning shock waves in the sun's atmosphere and what appear to be their properties?
2. Can such shock waves be examined experimentally?

Speakers: Bratonahl, Bruockner, Krall, Sakurai, Sturrock and Tendberg-Hanssen

Scientific Secretary: C. E. Newman

In addressing the first question, Sturrock listed three phenomena in which shocks may play a role: (1) the heating of the solar corona, (2) Athay-Morton waves, and (3) Type II radio bursts. In the coronal heating case, we know that some non-thermal mechanism is responsible, generally thought to be the dissipation of sound waves. One way in which shocks could be involved in this process has been reviewed by Kuperus (1969): as sound waves propagate upwards through the solar atmosphere, the density decreases; this leads to increase in the velocity associated with the wave amplitude; thus the Mach number of the wave increases, and shocks eventually develop. It was noted that this mechanism is self-stabilizing, because when these shocks are dissipated, they heat the atmosphere, leading to an increase in the sound speed and a lowering of the Mach number and a weakening of the shock. Thus probably only weak shocks are produced by this mechanism. Available data on the heating of the corona are in agreement with the formation of weak shocks.

Athay-Morton waves are observed as a disturbance, probably in the corona, propagating away from a flare site with a velocity of order 1000 km/sec; they are possibly shocks but can also be interpreted as fast-mode MHD waves. Type II bursts are sometimes associated with

flares which give rise to Athay-Morton waves; they have a duration of 20 - 30 minutes, with frequency decreasing with time. They are generally interpreted as a shock front, either a blast wave or a bow shock, moving upward. Smerd has explained the band splitting as radiation at  $\omega_p$  (and  $2\omega_p$ ) from the two sides of the shock which have different densities and hence different  $\omega_p$ , an interpretation which, if correct, is strong evidence for the existence of shocks in Type II bursts. Sturrock then outlined a model in which plasma ejected with the Alfvén velocity  $v_a$  from a flare site via reconnection propagates through a region of decreasing  $v_a$ , becoming super-Alfvénic and producing a bow shock which is the source of Type II radiation. A zero-order theory of stochastic acceleration in which a shock front shows that heavier particles are preferentially accelerated; this agrees well with observations of 100 - 1000 MeV particles, events thought to be due to Phase 2 acceleration in flares and which show enhancement of heavy ions and correlation with radio emission of Types II and IV.

Krall presented some studies of phenomena in shock waves which occur in the theta-pinch device. By numerical modeling, it is possible to reproduce theoretically the results of the laboratory over wide ranges of parameters. The modeling is done by using a fluid code to integrate the equations of motions, including the important mutual effects of fluctuations and macroscopic phenomena. The results of the study yield accurate results for magnetic diffusion times, magnetic field profiles, and ion temperatures; the electron temperature, however, is not in good agreement. The radiation at  $\omega_p$  and  $2\omega_p$  is not due to instabilities, since electrons in the shock front are accelerated en



masse and are unstable to frequencies near  $(m_e/m_i)^{1/3} \omega_p$  in the laboratory frame. Stochastic acceleration is also ruled out since the effects of this are simply to flatten out the distribution function at low (thermal) energies. A possible mechanism is the creation of a bimaxwellian electron distribution function via thermal mixing between cold plasma from the ends of the device with heated plasma in the vicinity of the shock; such a distribution is known to radiate much more at  $\omega_p$  and  $2\omega_p$  than a simple Maxwellian. All the processes discussed here are similar to those thought to occur in solar phenomena, so the agreement between these numerical studies and laboratory experiments suggests that extrapolation of these studies to solar parameters may be helpful in studying solar shock phenomena.

Bratenahl presented laboratory evidence for the production of a fast-mode MHD shock at an x-type neutral point when anomalous resistivity in the current sheet rises quickly to give enhanced diffusion of magnetic field from inside to outside. A blast wave of velocity  $10^8$  cm/sec is observed.

Sakurai then presented an analysis comparing moving Type IV bursts with Type II bursts and showed that the inferred speeds of the two disturbances were 200 km/sec and 2600 km/sec respectively. This wide disparity suggests that the two phenomena are due to different types of ejection -- the Type IV burst may be due to an emerging magnetic bottle and the Type II burst to a blast wave.

Tandberg-Hanssen gave an example of a spray-type moving prominence which showed evidence of shock formation. Pictures at successive times showed the prominence moving upward while associated Type IV radiation

was also observed moving with a velocity of 500 km/sec. Comparison of the prominence velocity with the shock speed gives Mach numbers of order 2 - 3.5. The radio burst was observed out to  $5 R_{\odot}$ ; a possible explanation for this effect is that the prominence sends a shock ahead of it at a faster velocity, so that the shock outruns the source and dissipates.

Finally, Brueckner showed pictures of a group of four clouds of gas taken at successive times. Extrapolation of these clouds back to the solar surface from their inferred velocity gives a time which agrees well with the times of emission from Type II bursts at various altitudes. The obvious interpretation is that a cloud is the driver gas or piston for a shock wave which gives rise to a Type II burst. However, it was not possible to say from the observations whether the shock precedes the piston or vice-versa.

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### Session 8.

1. What mechanisms are thought to be involved in radio emission from the sun?
2. Can any of these mechanisms be studied experimentally?

Speakers: Ko, Kundu, Loiby, Lin, de la Noe, Prasal and Rosenberg

Scientific Secretary: D.F. Smith

Rather than review the mechanisms of radio emission, Kundu gave a survey of the latest results from solar radio astronomy. The first of these is the "radio filament" --a depression in brightness in the mm-band which corresponds to an H $\alpha$  prominence. This Kundu interprets as the result of absorption by dense material. It differs from the H $\alpha$  prominence in that it is wider and lasts 1 - 2 days after the H $\alpha$  prominence disappears so that it may correspond to the prominence plus its cavity. Long baseline interferometry has recently been applied to the sun but has the disadvantage that it takes 10 - 12 hours to make a map of the whole disk. However, it has shown that the size of an X-band (3.7 cm) flare-associated burst is 2 arc seconds and thus will allow the gyro-resonance theory of the slowly varying component to be tested. Lang has shown that a few hours before a flare, the degree of polarization of 3.7 cm emission increases from 20 - 30% to up to 100% and the regions responsible become smaller at the time of a flare. There is no evidence of 300s periodicities at 3.7 cm and 11 cm, which Brueckner pointed out is consistent with the Harvard ATM data. There are bursts with drift rates intermediate between Type II and Type III bursts, which Rosenberg and Kuipers have interpreted as due to the combination of a whistler wave and a plasma wave. Kundu wanted to know the source of the whistlers.

while Smith pointed out that the inferred velocities given by Kundu are consistent with the present range of Type II velocities so that the new proposal may be unnecessary. Kundu mentioned the possible observation of the third harmonic and Smith noted that he had treated this process in 1970, but did not and still does not feel is worth much effort due to the extremely tenuous observations. Rust noted that he sees 2 - 3 arc second knots in  $H\alpha$  at the time of a flare, as well as point brightenings of this size before a flare, consistent with the x-band long-baseline-interferometry results.

Ko talked about interpreting stationary Type IV bursts, and pointed out the need for an improved synchrotron radiation theory, which takes into account the presence of the plasma and the mildly relativistic nature of the electrons. He pointed out an error in Wild's attempt to this.

Lin talked about simultaneous measurements of electron fluxes and Type III bursts near the earth. For small events there is a linear relation between  $\log T$  radio and  $\log$  (electron flux), whereas for bigger events there is a break after which the slope becomes 2.7. Lin does not detect the electrostatic waves calculated to be necessary to produce second harmonic radiation even for the most favorable case using the currently accepted random-phase approximation.

Prasad discussed what he calls "coherent amplification of Raman scattering" which Smith pointed out is a fixed-phase calculation of second-harmonic emission. Thus it is not surprising that he obtains much higher power than in the random-phase case and that the radiation is more highly collimated in direction. Smith noted that it would be

hard to test this theory with solar radio bursts because of scattering although the difficulties Lin reported may be taken as implying that a more efficient mechanism such as this one is needed.

Leiby described an experiment in which he measured fundamental and harmonic plasma radiation, with a frequency ratio of about 1.7.

Rosenberg considered interpretations of continuum bursts and noted that, except for moving Type IV bursts, plasma mechanisms were needed and described some of these. He reiterated the suggestion that a high time resolution spectrograph in the 300 - 1000 MHz range would be desirable to study the flare process and further noted that a floating zero level would be necessary to pick up fine structure.

de la Noe talked about Type 11b bursts which consist of chains of striations which Rosenberg suggested could be interpreted as the coupling of electron cyclotron and plasma waves.

SOLAR PHYSICS - PLASMA PHYSICS WORKSHOP  
STANFORD UNIVERSITY  
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