MEMORANDUM ON COSMIC STATIC

By

Grote Reber

The following is an idea which I have tried to sell to a variety of people from time to time. See Proc. I.R.E., August 1942, pp. 377-378. It seems that now might be a suitable time to get out a new and improved version and attempt to sell it again.

Back in 1939 Keenan and Henyey made some calculations on the expected intensity of radio waves from the Galactic center. These, they published in the June 1940 issue of the Astrophysical Journal. Their Fig. 1 on page 629 shows a curve which indicates the intensity of the radiation per unit band width would be substantially independent of frequency above 100 Mc/s. Thus the surface brightness of the sky will be about constant. For temperatures of 10,000 degrees the curve intersects the black body line a little below 100 Mc and the predicted intensity drops very rapidly as the frequency is decreased. As will be seen from the curve, my measurements at 160 Mc/s are in good agreement with the theory but the theory fails by approximately two orders of magnitude in predicting the intensity of Jansky's measurements at 16.7 and 20.5 Mc/s. This is because of the black body limitation imposed by the theory at the lower frequencies. Some years later C. H. Townes of the Bell Telephone Laboratories covered the same ground using a somewhat different approach and came to the same conclusion that Keenan and Henyey did. In order to account for the intensity measurements by Jansky at 16.7 and 20.5 Mc/s and later by Friis and Feldman at 9.5 Mc/s, Townes indicated that electron temperatures on the order of 100,000 degrees would be necessary.

Greenstein says opacity varies as frequency to minus two power

According to information supplied to me by various astronomers electron temperatures of 100,000 degrees are absolutely out of the question in interstaller space. The reasons for such statements are: (1) That if such temperatures did exist, the stationary lines due to gaseous absorbing material, in space would be very much broadened, far more so than is presently observed; (2) If temperatures of 100,000 degrees existed the material of space would be in a much higher ionized condition than is presently observed. Since these higher levels of ionization should be readily observable if they exist and since the broad absorption line widths should also be readily measureable, it is concluded that temperatures on the order of 100,000 degrees are absolutely out of the question. Upon further questioning I find that even 10,000 degrees is very optimistic. Apparently, only a few and specially selected regions in space are available which show even 10,000 degrees, that in general a more reasonable temperature would be perhaps 5,000 degrees or even 3,000 degrees. These figures were supplied to me by Oort, Van de Hulst, Stromgren and Greenstein. Consequently, I feel that some other explanation than merely assuming an arbitrarily high temperature must be involked to explain the intensity of the radio waves arriving from the Galaxy at frequencies below 100 Mc/s.

The astronomers take the attitude that Jansky made a mistake in his measurements and quoted an intensity far in excess of the true value. During the last year, experiments have been conducted at the Bureau and reported on by Johler at the last URSI conference. See attached program. These measurements were taken at frequencies of 110, 75, 50 and 25 Mc/s

and Nature 3rd april 1948, Vol 161, p 515-516
and Proc. IRE, august 1942, Vol 30, p 377-378

using simple antennas with very wide acceptance patterns. The integrated intensities from large areas of the sky indicate that the intensity per unit band width, per unit area on the earth, per unit area in the sky is substantially independent of frequency. The figure they quote is $F^{-0.4}$ power. Thus it is apparent that Jansky was not in error and that the high intensities measured by himself and Feldman at low frequencies really do exist.

Referring back to Fig. 1 of Keenan and Henyey it will be observed that if the horizontal portion of their curve were extrapolated to the left beyond the black body limitation the extrapolated curve would pass directly between Jansky's two points at 16.7 and 20.5 Mc/s. Furthermore it would bring Friis data at 9.5 Mc/s into line.

Now in order to achieve this desirable result some way must be found to overcome the black body limitation imposed by the theories of Keenan and Henyey and of Townes. Attached to this memorandum are some figures. Figure 1 indicates a cube of material which is at some temperature T. This cube may be of any material as the conductivity of the material is of relatively minor importance as far as the following remarks are concerned. Across the top and the bottom faces of the cube are conducting plates and across these plates will be developed a random voltage due to the thermal agitation of the charges within the cube. This random voltage is shown as an irregular wavy line above the top wire. The wires leading from the top and the bottom faces of the cube enter another little rectangle which represents a frequency descriminatory circuit. This circuit may be tuned to any frequency at which we may be interested and at every frequency it will always pass the same band with B. At the output of this frequency selective circuit will appear a more homogeneous wave as represented by the cyclic curve above the wire going out of the rectangle. The output of the frequency selective circuit is measured by a voltmeter V. Now the power indicated by the voltmeter, V, will be proportional to the voltage squared, and will be in turn, proportional to T times B times F^0. In other words the power per unit band width available at the output terminals of the frequency selective network will be independent of the frequency to which the network is tuned.

At the left side of the figure is another combination of apparatus. This represents a different technique for measuring the activity of the electrons within the cube of material. The material is assumed to radiate according to the conventional Rayleigh Jeans formula at low frequencies. The radiation will be random and consequently represented by an irregular wavy line leaving the front face of the cube. This radiation now passes through a grating or prism or any suitable frequency selective device, such that a very narrow band of wavelengths is passed through and all others rejected. The radiation leaving this frequency selective material will be much more coherent and is represented by a cyclic wave leaving this frequency selective material. The output radiation is then allowed to fall upon a thermo couple whose output is recorded by an ammeter, A. The output power is proportional to I^2 which in turn is proportional to T times B times F^2. In other words, if the frequency selective material is altered so that different frequencies are allowed to pass it will be found that in intensity per unit bandwidth is proportional to the square of the frequency to which this frequency selective material is tuned. Now these are the circumstances or set of conditions imposed by the theories developed by Keenan and Henyey and by Townes. These circumstances are somewhat different than those at the right of the picture which represent the circumstances surrounding the actual measurement techniques used by the radio engineers. For some reason the results of these two schemes of measurement do not produce the same results when analyzed in the above fashion.

In an attempt to rationalize the above difficulties I have conceived of the following scheme shown in Figs. 2, 3, and 4. Figure 2 shows the conventional cube of material with a voltmeter, V, measuring the available power across the top and bottom faces. The cube will have a random voltage generated between its top and bottom surfaces by virtue of the fact that the free electrons within the cube are in random motion. Electrons which move in directions Y and Z will not affect the charge upon the top and bottom faces of the cube. Only electrons which move in direction X will affect the charges upon these faces. It is these random motions along the X direction which are measured by the voltmeter, V. Any random motion along the Y and Z directions will go without notice, as far as the voltmeter is concerned. Figure 3 is another picture of this same cube. Within the cube is a dipole having leads from the center of the dipole and brough out to another voltmeter, V.

Consider the cube to be filled with an electron gas in random motion. This electron gas is the equivalent to the free charge within a conductor. Electrons which move in directions Y and Z will not induce currents in the dipole. Only electrons which move in the X direction will cause a current to flow in the dipole. This current will cause the voltmeter, V, to be actuated. Figure 4 is an attempt to explain how the motions of the electrons in the box may be measured at a distance. The electrons in the box are in the same random motion as above. If an electron were in uniform motion and had no change in velocity and direction there would be no effect as far as the remote dipole at the left hand side of the figure is concerned. Actually it is the changes in direction of an electron which makes the system work. If all the electrons in space moved in a straight line with uniform velocity the situation would be entirely a dc phenomenon. The pulse of electro-magnetic energy is radiated when an electron changes its direction momentarily. Consider fig. 5, where we have a wire, W, and an electron, E, traveling in a U shaped path. When the electron is moving toward the wire a uniform change is induced and no effect occurs. For a brief instant the electron moves parallel to the wire and causes a counter current to flow in the wire. During this time the electron may be considered a primary current of a transformer and the antenna wire a secondary winding. Later the electron moves away from the wire and the net effect of the movement away is to cancel the original uniform charge caused by the original approach of the electron. Only the electrons with a momentary velocity parallel to the wire will be effective. If the electron comes toward the wire and turns downward (so the momentary velocity is across the wire) and goes away, or if the electron describes another similar curve into the paper, so that again the momentary velocity is across the wire then the secondary winding is not coupled to the primary current and the motion of the electron will go unobserved by the antenna.

Referring back to figure 2, the magnitude of E^2 is proportional to R. In other words a little cube of low resistivity material which has many free electrons per cubic cm will produce the same resistance as a large cube of high resistivity material which has few free electrons per cubic cm. By analogous reasoning in figure 3, equal results would be secured by using a little box with many free electrons per cubic cm or a big box with few free electrons per cubic cm. Just how these factors are related I am not sure. I believe that the dimensions of the box merely need to be large compared to the mean free path of the electrons. Further, the mean free path needs to be large compared to the size (wavelength) of the antenna. Perhaps a better statement is that the mean time between collisions needs to be long compared to the period of the wave in question. In any case there is some criterion which determines when the antenna is properly immersed in the free electrons. This means an optical depth of unity. Making the box larger than this minimum will not effect the phenomena. If the box is too small and the electrons too few the system breaks down. This means an optical depth less than unity.

The third step in Fig. 4 involves the principle of optics, that the temperature of the image is related to the temperature of the object and in the limit the temperatures of the image cannot be greater than the temperature of the object. Thus no greater illumination can be secured at the position of any image than if the object were placed at that position. So, by a suitable optical system, we may take the antenna of Fig. 3 out of the box and place it at a distance therefrom as in Fig. 4. In between we will put an optical system so that everything that goes on in the box which the antenna was originally susceptable to will cause an equal effect at the image point. The antenna is still effectively immersed in the electrons of the box even though the box may be 10,000 parsecs away. (Note: Simple lens shown won't do the trick but a suitable mirror and focal device will).

Now back in Fig. 3 we found that only the electrons surging along the X axis parallel to the wire were effective. The same will still be thecase of the electrons in the distant box. These electrons will be sending out pulses of electromagnetic energy of random polarization in all directions. Only those pulses with the electric vector parallel to the antenna wire will be received. If the electric vector is perpendicular to the wire or along the line of sight the pulse will not be received. This is merely another way of saying only electrons surging along the X axis of box are effective. For my experiments the X axis is parallel to the celestial equator. Perhaps all the above is a complicated way of saying that the Nyquist formula of $P \propto f^0$, is the one dimensional equivalent of Rayleigh-Jeans three dimensional law $P \propto f^2$.

Grote Reber
July 1, 1948

integral equations, in the representation of noise through linear and square-law detectors, leads to a synthesis of these various nodes in a discrete matrix representation.

19. EMISSION OF RADIO-FREQUENCY ENERGY FROM THE SKY.—A. E. Covington, *National Research Council, Ottawa, Canada.*—Further observations of sudden changes in the microwave radio-frequency energy received from the sky, support an association with certain magnetic disturbances, as reported by the author in Terrestrial Magnetism and Atmospheric Electricity (Sept. 1947). The presence of two types of storms may indicate different modes of generation. One type shows an increase in the equivalent temperature of the sky, sometimes as large as 200°C; while a second type shows temperature fluctuations about an average background sky temperature of approximately 50°C. Some recurrent noise storms show identical structure. A noise storm on 200 megacycles coincided with the auroral display of July 26, 1946.

20. BROAD-DIRECTIVITY MEASUREMENTS OF COSMIC RADIO NOISE AT VERY HIGH FREQUENCIES.—J. R. Johler, *National Bureau of Standards, Washington, D. C.*—This paper describes the equipment designed and constructed at the Sterling (Va.) Radio Propagation Laboratory of the National Bureau of Standards for measuring the intensities of cosmic radio noise at several frequencies in the very high frequency range. Construction of the equipment, provisions for its calibration, and the precautions taken to maintain the stability of equipment, are discussed. Some of the preliminary results obtained using this equipment are presented, especially those pertaining to the variation of cosmic noise intensity with frequency.

21. MICROWAVE ATMOSPHERIC ABSORPTION AND COSMIC NOISE.—M. Schulkin, *Naval Research Laboratory, Washington, D. C.*—A detailed examination has been made of Dicke's microwave radiometer data at wavelengths of 1.00 cm, 1.25 cm, and 1.50 cm, in the light of later microwave absorption studies of water vapor and oxygen. The limitations of Dicke's analysis are discussed. It is shown that exact conclusions can only follow from independently determined oxygen absorption, water vapor absorption and cosmic noise data. Accepting the published water vapor absorption data, limits are placed on the possible magnitudes of cosmic noise and oxygen absorption at these frequencies.

Evening Session

MICROWAVE SYSTEMS

Monday, May 3, at 8 P.M.

22. 6000-MEGACYCLE TELEVISION RELAY SYSTEM.—William H. Forster, *Philco Corporation, Philadelphia, Pa.* (1 hour).— By way of introduction the paper will review some of the steps in the development of television radio relay systems which have been made since 1940. The salient characteristics and advantages of microwave relays, particularly for networking television, will be illustrated by considering the relay networks now in service.

The main body of the paper will discuss the new Philco television relay equipment which operates in the 6000-megacycle common carrier band and

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15. CALCULATION OF THE ATTENUATION OF ELECTRICAL FIELD STRENGTH.—Harold J. Peake, *Naval Research Laboratory, Washington, D. C.*—A procedure has been devised to facilitate the calculation of electric field strength curves for frequencies above 150 Mc in transmission through a "standard atmosphere" over a spherical earth. The amount of actual computation required has been minimized by presenting much of the data in pre-caluculated tables and curves. By use of the procedure and material presented, a curve of theoretical attenuation vs distance can be obtained in a comparatively short time. The equations used are derived from those of Norton and Pekeris. Sample curves are given.

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16. ELIMINATION OF REFLECTED SIGNAL EFFECTS IN PULSED SYSTEMS.—Dayle O. Collup, *Naval Research Laboratory, Washington, D. C.*—Experience with microwave equipments depending upon pulse width or pulse spacing to convey information, has shown them to be susceptible to distortion due to the presence of reflected signals. This effect is aggravated in the case of equipment employing broad-beam or omni-directional antennas, since reflected energy can enter the system from a greater range of angles. With pulse widths 0.5 to 2.0 microseconds, a path-length difference of the order of several hundred feet can cause the effective pulse length to be doubled in the presence of a reflected signal.

A method for suppressing all significant reflected signals, even in extremely unfavorable locations, is described, and the results of laboratory and field tests given.

Applications should be found in the pulse communication and trans-pondor beacon fields.

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17. NEW RADIOSONDE FOR UPPER-AIR MEASUREMENTS.—Leo Craig, *Meteorological Branch, Evans Signal Laboratory, Belmar, N. J.*—The Signal Corps Engineering Laboratories have developed a balloon-borne radiosonde which provides more accurate meteorological data on temperature, humidity, pressure, wind speed, and wind direction. The equipment operates at 1680 Mc and is tracked by an automatic direction finder.

A semi-conductor temperature element coated with a material which is highly reflective to solar radiation has been reduced in diameter to secure additional sensitivity and increased in resistance to decrease the power dissipation.

The conventional salt-solution humidity element has been improved by materially reducing the error due to polarization.

The pressure unit consists of a capsule which is more sensitive and more accurate in the low-pressure, high-altitude region; the measuring assembly includes an improved commutator providing greater sensitivity.

The transmitter has been designed in a streamlined form with the use of miniature components. The audio oscillator provides good stability of the measuring circuits under the varying conditions of temperature, humidity, and battery voltage. The transmitter has adequate power output and a uniform radiation pattern conducive to more accurate direction finding by the ground equipment.

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18. TECHNIQUES IN THE ANALYSIS OF NOISE.—Duncan Harkin, *Naval Research Laboratory, Washington, D. C.*—A discussion of the roles of Fourier series and transforms; Markoff stochastic processes; and Fredholm

Additional Paper: - Following Paper No. 21, Monday Afternoon: "Ten-Centimeter Solar Radiation as Correlated with Sunspots", by Mr. J. F. Denisse, Ecole Normale Superieure, Paris, France

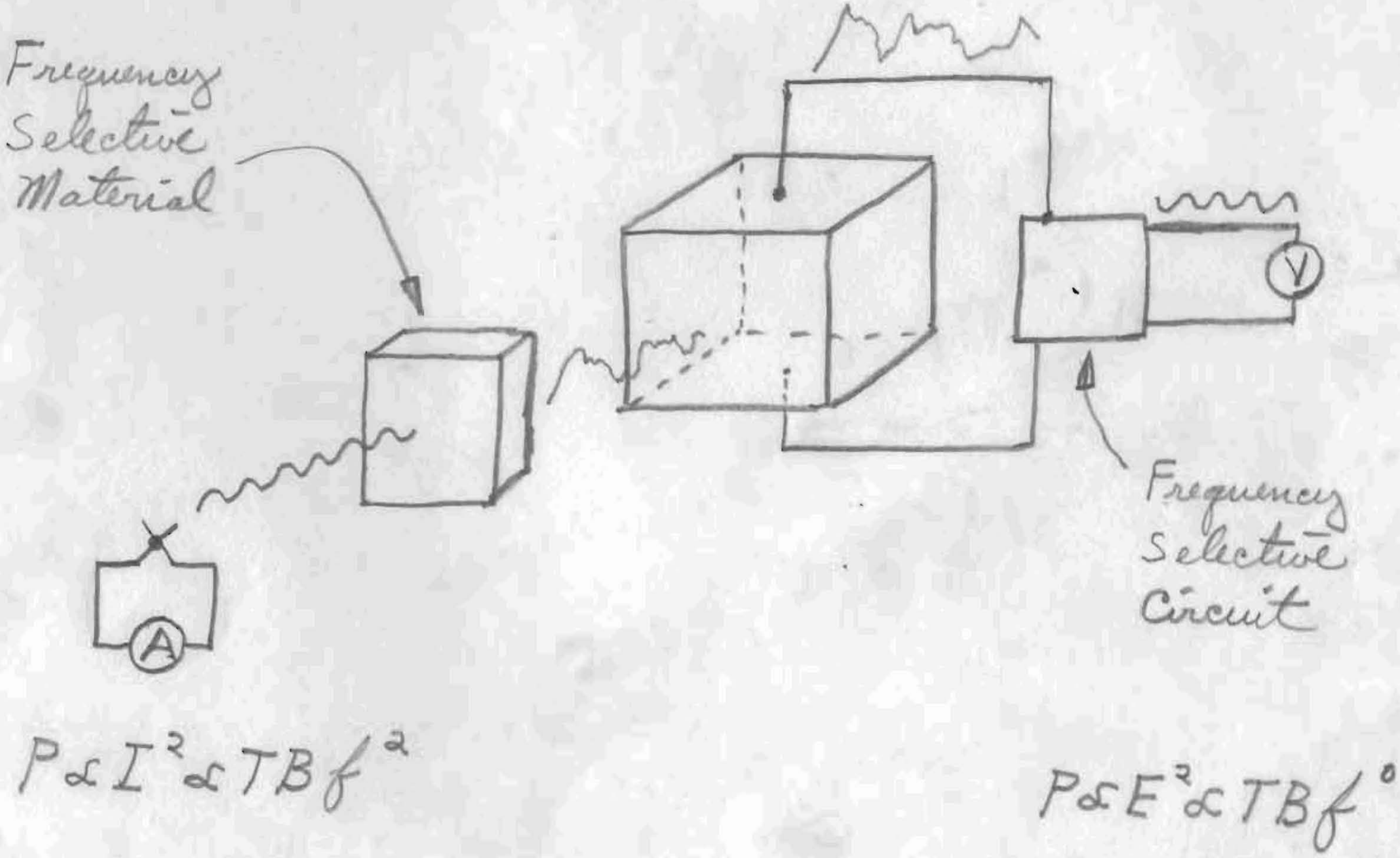
Frequency Selective Material
A
V
Frequency Selective Circuit
$P \propto I^2 \propto TBf^2$
$P \propto E^2 \propto TBf^0$

Fig 1

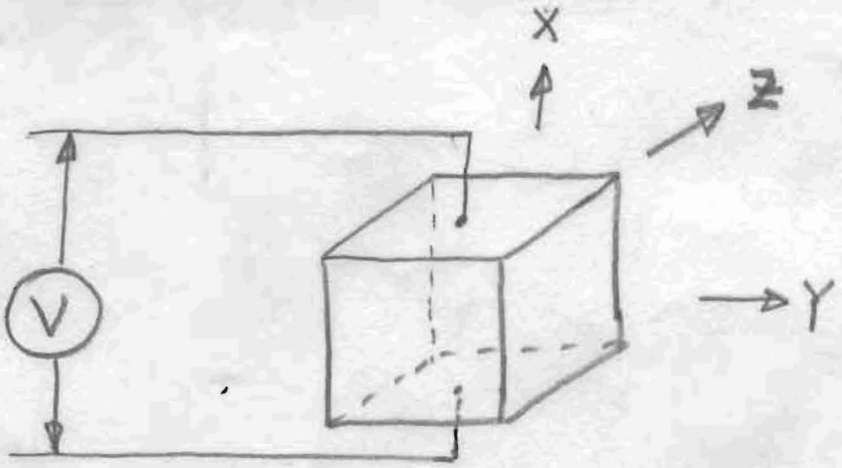

Fig 2

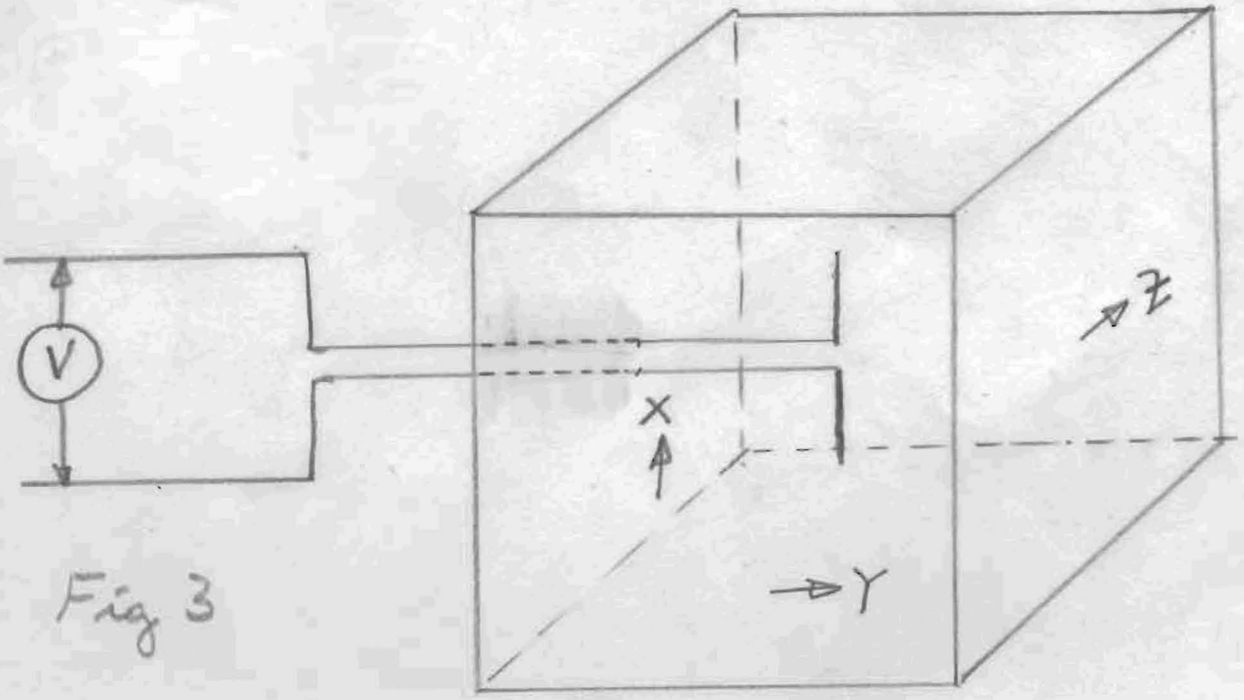

Fig 3

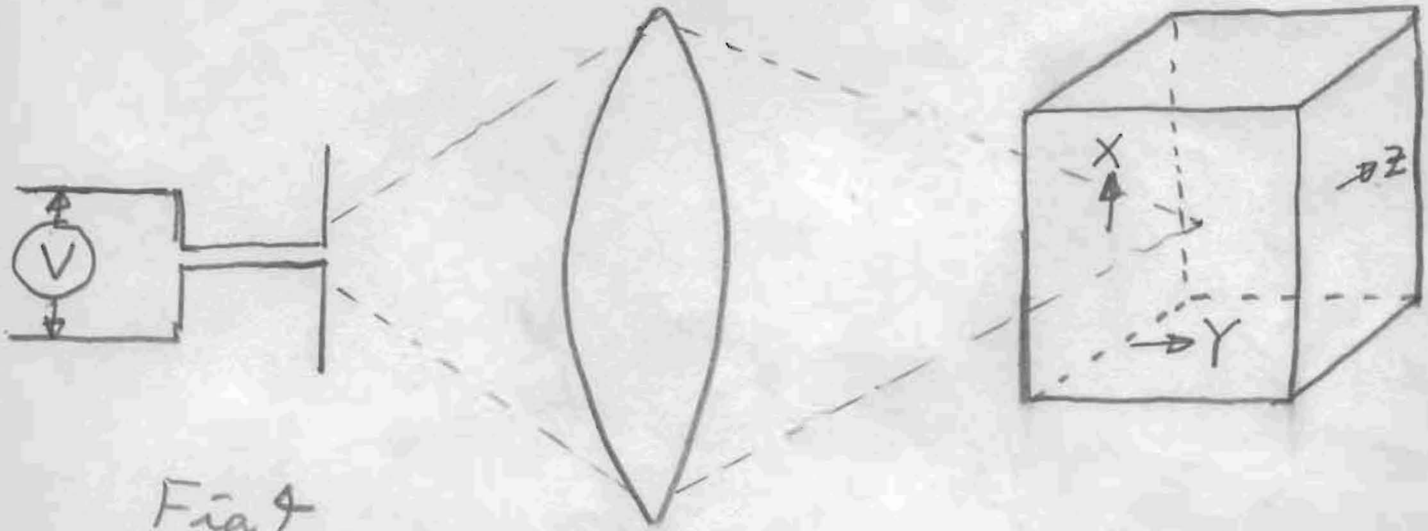

Fig 4

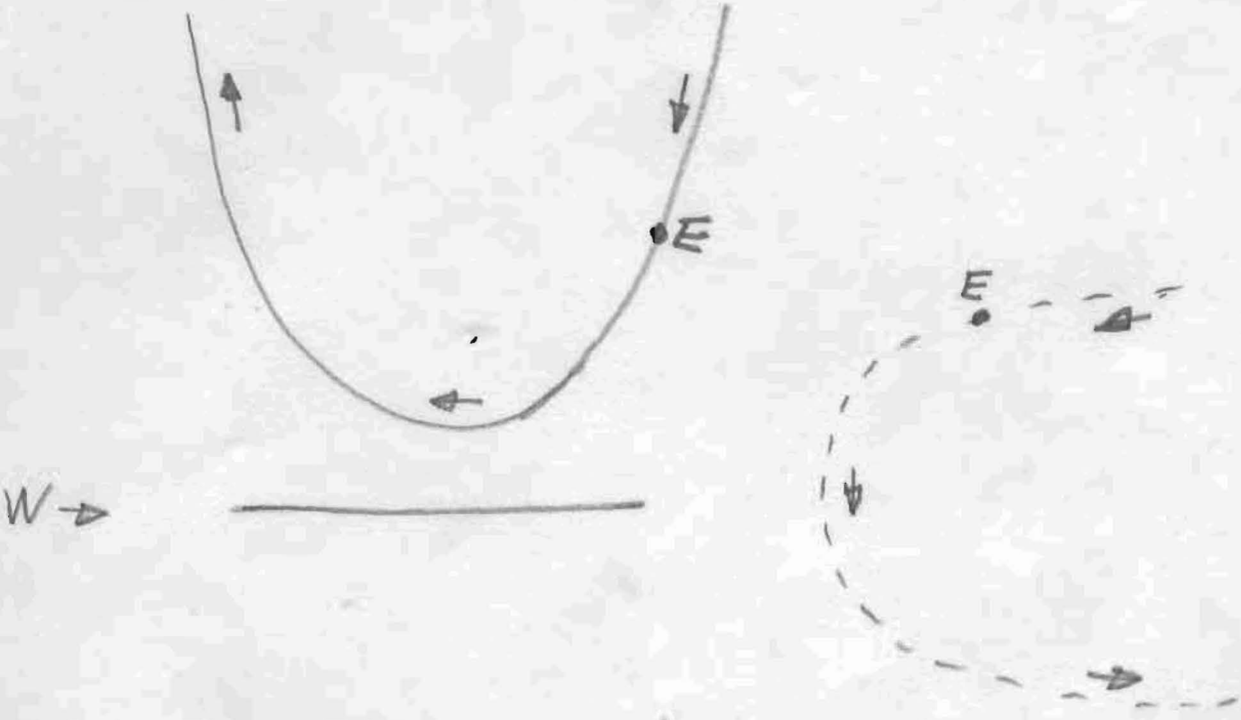

Fig 5