Fall 1968

A Report of Work for H492

Claudia Morgan Griffin

A REPORT OF WORK DONE FOR H492

Fall Semester, 1968

Presented to

Jack Patrick

by

Claudia Morgan Griffin

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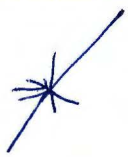
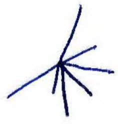
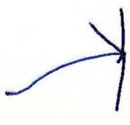
INTRODUCTION

My research project for this year is to study nuclear emulsion plates sent to the physics department by Dr. David Young of Mississippi State University and to learn as much as possible about the fields related to the project. These plates are exposed to cosmic rays at altitudes, for all practical purposes, above the earth's atmosphere. They are then collected and processed. They will be sent to us so that we can scan them next semester.

The first semester's part of the project was to scan a sample plate and to do a literature research of related fields. Therefore, this paper is not a formal research paper on one topic, but instead a sample of scanning and outlines of the books I have read.

EXPLANATION OF SCANNING DATA

This is the scanning of a plate Dr. Young sent us from the top of the plate to the co-ordinate Y=10. It will be used to determine my bias, information which will be used in later scannings. In the drawings, generally the longest rays indicate the incoming particles. The code for the direction is "g" if the incoming ray comes from the glass side of the plate and "a" if it comes from the air side.

No	Description		x	y	Remarks
	drawing	direction			
1		g	87.6	5.0	
2		g	86.2	5.1	Looks strange: not sure it's an event
3		?	77.3	5.5	
4		g	79.8	5.6	
5		g	81.2	5.7	
6		g	90.4	5.5	
7		g	92.1	5.5	
8		g	94.4	5.5	
9		a	95.6	6.6	

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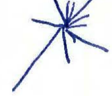
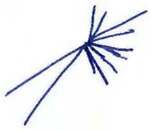
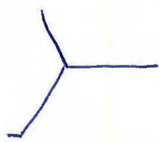
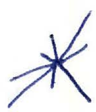
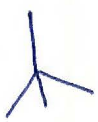
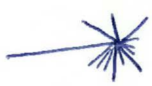
10		g	94.5	6.4	
11		g	93.0	6.5	
12		g	89.4	6.5	
13		?	88.0	6.5	
14		?	82.9	6.3	
15		?	75.0	6.5	Incoming track very light. others heavy
16		a	80.2	7.6	
17		g	80.8	7.3	Short
18		g	81.8	7.4	

Page 3

No	Description		x	y	Remarks
	Drawing	direction			
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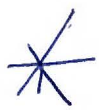
20		g	83.7	7.6	
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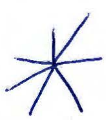
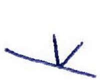
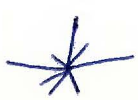
22		a	90.3	7.2	
23		a	92.5	7.9	
24		?	93.1	7.4	
25		a	96.6	7.4	
26		g	98.0	7.4	
27		a	100.0	7.3	Close to top

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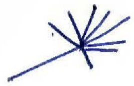
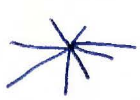
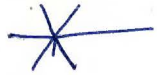
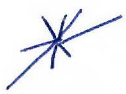
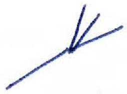
28		a	99.1	7.8	Heavy, close to top
29		a	98.3	7.9	Close to top
30		a	98.1	8.0	close to bottom
31		?	95.8	8.0	Short
32		g	95.0	8.0	
33		a	~~33.~~ 92.5	8.0	Close to top
34		a	88.2	8.0	Close to top
35		?	87.8	8.2	May be several particles colliding
36		?	84.6	7.9	

No	Description		x	y	Remarks
	Drawing	Direction			
37		?	82.7	8.0	Looks like a spider web
38		?	79.6	7.9	short
39		?	79.4	8.0	heavy
40		g	70.5	8.2	
41		g	72.3	8.6	
42		a	75.3	8.2	
43		a	80.8	8.4	
44		g	83.5	8.3	
45		g	85.5	8.2	

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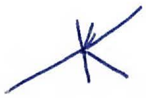
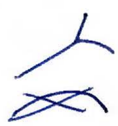
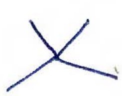
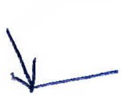
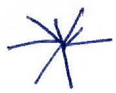
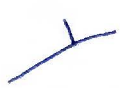
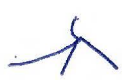
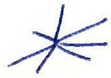
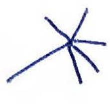
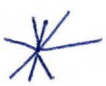
46		?	94.6	8.5	
47		g	99.0	8.2	Long secondaries
48		?	99.3	8.4	Short
49		a	95.4	9.0	
50		g	93.2	8.9	
51		g	91.3	9.1	Not sure it's an event
52		?	89.1	9.2	
53		?	88.1	9.1	Heavy
54		?	87.8	9.0	

No.	Drawing - Direction		x	y	Remarks
55		?	87.7	8.9	
56		g	87.0	9.1	
57		a	86.8	9.1	Close to top
58		a	84.3	9.1	
59		a	83.5	8.9	long
60		?	82.3	8.8	Not sure an event
61		?	81.6	9.0	Not sure an event
62		?	74.9	8.8	
63		g	74.1	9.2	

No.	Drawing - Direction		x	y	Remarks
64		a	69.8	9.8	
65		a	74.5	9.8	Close to top
66		a	74.5	9.6	Close to top
67		g	75.7	9.7	
68		g	77.8	9.5	
69		?	84.7	9.5	Big
70		a	85.1	9.6	
71		g	86.8	9.8	Near top
72		a	88.5	9.6	

No.	Drawing-Direction		x	y	Remarks
73		?	89.2	9.5	
74		?	90.7	9.3	
75		g	90.7	9.4	
76		?	93.7	9.4	Close to top
77		a	95.5	9.7	
78		a.	102.3	9.7	Light
79		?	100.8	9.7	
80		g	99.4	9.9	
81		?	92.2	9.8	Close to bottom

No.	Drawing - Direction		x	y	Remarks
82		a	78.6	9.6	
83		?	87.4	9.6	
84		?	77.5	9.8	
85		?	78.4	9.8	
86		?	75.4	9.8	Next to top
87		?	67.5	9.7	
88		?	79.9	7.0	
89		?	83.5	7.0	
90		g	89.4	7.0	Secondaries short

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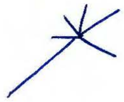
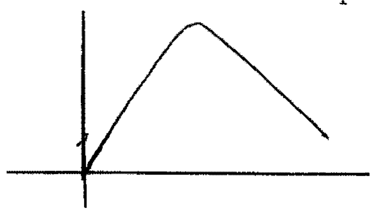
No.	Drawing - Direction		x	y	Remarks
91		?	99.1	7.1	Close to top

Rossi, Bruno. Cosmic Rays. New York: McGraw-Hill Book Company, 1964.

VII.[1] Electrons, photons, and showers

A. Shower curve. When the particles go through a thickness of lead, the coincidence per hour versus the thickness of lead is plotted like so:



B. Theory of Hans A. Bethe and W. Heitler, both of England, in 1934.

1. A Charged particle passes near an atomic nucleus, and its trajectory is bent by the strong electric field associated with the positive electric charge of the nucleus.

   a) Radiation losses are enormously greater for light particles than for heavy ones. Particles radiate as a result of accelerated motion. The greater the mass, the smaller the acceleration.

   b) For a given mass per unit area, radiation losses are much greater in elements of high atomic number than in elements of low atomic number. The deflecting force experienced by a particle passing near a nucleus is proportional to the electric charge on the nucleus.

   c) Radiation losses increase with energy. Ionization losses at first decrease with increasing energy, then they become more and more constant.

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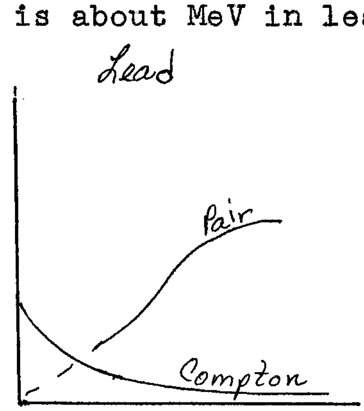
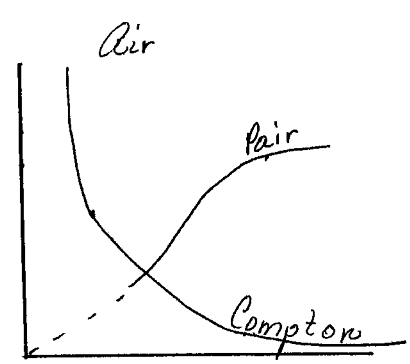
[1] In most cases the Roman numeral indicates the chapter number.

Therefore, as the energy increases, radiation losses will eventually overtake ionization losses. For electrons, this is at about 10 MeV in lead and at about 100 MeV in air.

2. Photons produce pairs of positive and negative electrons. Bethe and Heitler studied this process.
   a) For a given photon energy, the probability of pair production in layers of different elements with the same mass per unit area increases rapidly with the atomic number of the element. This is for the same reason as in 1b.
   b) The probability of pair production in a given thickness of matter first increases rapidly with increasing photon energy and then levels off at a nearly constant value. The probability of Compton collisions decreases steadily (not with a constant slope) with increasing energy. At low energies photons are absorbed mainly through the Compton effect, and at high energies mainly through pair production. The energy at which pair production overtakes the Compton effect is about MeV in lead and 20 MeV in air.





C. Shower theory--cascade process

A photon produces a positive and a negative electron. Each emits a photon, and more as it slows down. There is a chain reaction. But individual energy slowly gives out, and the reaction dies.

VIII. Mu Meson--discovered in 1937

A. Penetration of the mu meson is larger than that of the electron.

B. The mu meson has the same charge as that of an electron, has a mass about two hundred times that of an electron, and has a mean life of $2x10^{-6}$ seconds.

C. The density of droplets along the cloud-chamber track of particles gives the ionization of a particle.

D. Local cosmic radiation: Penetrating particles are mu mesons. Absorbable particles are electrons. Nonionizing particles are photons.

E. The mean life is 1.4 times the half life. The mean life is the average life span of a particle.

F. The neutrino is a particle with no mass and no electric charge.

IX. Pi mesons

A. Negative mu mesons are captured by nuclei (Stars on emulsion plate). Positive mu mesons decay naturally. In light elements not all the negative mu mesons are captured. This is one mystery that lead to the discovery of the pi meson.

B. $\pi^+ \xrightarrow{\text{decays to}} \mu^+ + \nu$

$\pi^- \longrightarrow \mu^- + \nu$

$\mu^+ \longrightarrow e^+ + \nu + \bar{\nu}$

$\mu^- \longrightarrow e^- + \nu + \bar{\nu}$

ν =neutrino
$\bar{\nu}$ =antineutrino
e =electron

C. When a π^- meson is captured by a nucleus, it does not have time to decay before it explodes because energy is given off when it stops. In nuclear emulsions, a star appears where a π^- meson is captured and the parts of the nucleus are scattered.

D. The mass is 273 electron masses. The mean life is 2.55×10^{-8} second.

E. Pi mesons interact more frequently with atomic nuclei than do mu mesons.

F. Neutral pi mesons.

1. Mass = 274 electrons
2. Mean life = 2×10^{-16} second.
3. $\pi^\circ \longrightarrow \gamma + \gamma$ γ = photon (γ ray)

X. Nuclear interactions of cosmic rays

A. High-energy electrons, photons, and mu mesons form the bulk of the cosmic radiation near sea level, for they do not interact appreciably with atomic nuclei. The strongly interacting particles are protons, neutrons, and pi mesons that do not decay first into mu mesons.

B. Two groups of new particles are heavy mesons and hyperons. Both may be neutral or electrically charged. Neither occur singly.

1. Heavy mesons

   a) These are lighter than protons, but heavier than pi mesons.

   b) They may be produced in nuclear collisions by a direct process of materialization of energy.

2. Hyperons

   a) These are heavier than protons.

   b) A high-energy proton or neutron may turn into a hyperon when it strikes an atomic nucleus, giving rise at the same time to a heavy meson.

C. A neutral lambda particle (Λ)--a hyperon--decays into a proton and a negative pi meson:

$$\Lambda \longrightarrow p^{+} + \pi^{-}$$

D. Positive sigma particles--hyperons--decay into neutrons and positive pi mesons:

$$\Sigma^{+} \longrightarrow n + \pi^{+}$$

E. Heavy meson--positive

$$K^{+} \longrightarrow \pi^{+} + \pi^{+} + \pi^{-}$$
$$K^{+} \longrightarrow \pi^{0} + \pi^{0} + \pi^{+}$$
$$K^{+} \longrightarrow \pi^{0} + \pi^{+}$$
$$K^{+} \longrightarrow \mu^{+} + \nu$$
$$K^{+} \longrightarrow \mu^{+} + \pi^{0} + \nu$$
$$K^{+} \longrightarrow e^{+} + \pi^{0} + \nu$$

F. Antiprotons and antineutrons are like positrons.

XI. What cosmic rays are and what they do in the atmosphere. Primary cosmic rays are naked nuclei. Their energies are distributed over a broad spectrum. Their trajectories are bent by the earth's path (latitude effect). More come from the west than from the east (east-west effect). On the average, protons collide after going about 70 g/cm^2, or 1/14 the air mass above sea level. Alpha particles go 25 g/cm^2. Heavier nuclei go even smaller distances.

XII. Giant showers of the atmosphere

A. The minimum energy necessary to produce a shower observable at sea level is about 10^{14}eV.

B. The only way to study the high-energy region of the cosmic-ray spectrum is to observe air showers.

XIV. Cosmic rays and the sun

A. The most spectacular solar event ever recorded by ground-based instruments took place on February 23, 1956 (13 years ago--near solar maximum). A great solar flare appeared. In 15-20 minutes cosmic-ray counting machines went crazy. The higher the altitude, the greater the detection. Some increased to between 25 and 40 times normal. But detectors near the equator recorded increases of only a few per cent. This increase was due to a stream of high-energy particles ejected by the sun at the time of the solar flare. The radiation originating from the flare contained comparitively more low-energy particles than did ordinary radiation. This is shown by the difference in increase with respect to latitude. It takes high-energy particles to penetrate the earth's magnetic field.

B. 1956-57 was the International Geophysical Year. During this time there was a sudden increase in atmospheric ionization over the polar caps an hour or so after the appearance of a large solar flare. Other tests were made, and with the same results.

C. The particles produced in these events continue to rain upon the earth for a period of hours after the disappearance of the flare from which they arose. Apparently the particles cannot escape directly from the solar system, but they are trapped temporarily within it.

D. The particles observed immediately after the flare often appear to approach the earth from a fairly well-defined direction. Toward the end of the event the particles seem to come from all directions. The "early" particles are those coming directly from the sun (bent some by interplanetary magnetic fields), and the "late" particles are those that have bounced back and forth several times in space before reaching the earth.

E. Solar activity also affects the flux of high-energy particles entering the solar system from outside. This is called Forbush decreases. About one day after a solar eruption the earth experiences a magnetic "storm." There is a short increase of the order of one part per thousand in the strength of the earth's magnetic field (sudden commencement) followed by a decrease of the order of several parts per thousand for a few hours (main phase). The magnetic field slowly recovers its original strength over a period of days. Some storms are accompanied by Forbush decreases. Cosmic-ray intensity begins to decrease at the same time as the magnetic field, reaching a minimum a few per cent below normal. As the magnetic field returns to normal, so does the cosmic-ray intensity. This is a world-wide effect. Therefore, whatever produces the decreases must effect both high-energy and low-energy particles. Also, along with these changes often comes large-scale changes in the outer radiation belt. Radiation intensity drops sharply at first, particularly in the far region of the outer belt. Simultaneously, widespread aurorae appear. After a day or two the outer belt returns to normal. The number of particles overshoots the prestorm level and then decreases gradually. After a few weeks the outer belt returns again to normal.

F. The something from the sun:

1. Produces magnetic storms.
2. Partially shields the earth from oncoming cosmic-ray flux.
3. Causes auroral displays.

4. Changes the outer radiation belt.
5. Carries with it the energy needed to rebuild that belt.

G. Theory of these particles: Out of the solar corona comes a constant stream of diluted, highly-ionized gas (plasma), consisting mainly of hydrogen. Because of this there exists in interplanetary space a more or less steady "wind" of plasma (solar wind). Near the earth the speed of the wind is several hundred km/sec, and the density is several particles/cc. The "explosions" responsible for the solar flares occur at the base of the corona, in the region immediately above the photosphere, the visible disk of the sun. Much of the energy released appears as additional kinetic energy in the dense plasma at the base of the corona. As a result, a cloud of plasma is driven through the corona into interplanetary space at a speed of about 1,000 km/sec. As it pushes against the solar wind, which is moving at a slower speed away from the sun, the cloud produces a shock wave. When this wave hits the earth's magnetic field, it compresses the lines of force and causes the sudden commencement (increase in strength of field). It also puts wiggles in the distant lines of force, where the field is weaker and more easily disturbed. This gives a possible escape to the trapped particles of the outer belt. Solar plasma is injected by the shock wave into the magnetosphere (the region where the magnetic field predominates over the interplanetary field). This may cause the main phase of the magnetic storm. Also, the wave may increase the individual energies of the plasma particles already in the magnetosphere. Anyway, the plasma pressure increases, and the lines of force move farther apart, and the field's strength decreases. This injection, or heating, is probably closely related to the recovery of the outer Van Allen belt.

H. As the altitude increases, the difference between cosmic rays at solar minimum and those at solar maximum increase. Therefore, whatever causes the increase affects mainly low-energy particles.

XV. The origin of cosmic rays--an unsolved problem.

XIV. Appendix

A. One eV is the amount of kinetic energy of an electron accelerated by a potential difference of one volt.

B. Elementary particles

1. Photon--the quantum of electromagnetic radiation.
2. Pi meson--the quantum of the nuclear fields of force.
3. K mesons--"heavy" π mesons.
4. Ξ--xi particles, Λ--lambda, Σ--sigma.
5. Leptons and baryons are conserved. (But they are not interchangable, as are mass and energy.)

Family	Group	Particle - Anti-particle	Mass (m_e)	Charge	Mean life (sec)	Decay Modes
Photons	Photons	γ — γ	0	0	stable	
Leptons	Neutrinos	ν_e	0	0	stable	
		$\bar{\nu}_e$	0	0	stable	
		ν_μ	0	0	stable	
		ν_μ	0	0	stable	
	Electrons	e^-	1	−	stable	
		e^+	1	+	stable	
	μ mesons	μ^-	206.8	−	2.212×10^{-6}	$e^- + \bar{\nu}_e + \nu_\mu$
		μ^+	206.8	+	2.212×10^{-6}	$e^+ + \nu_e + \bar{\nu}_\mu$
Pi + K mesons	π mesons	π^0 — π^0	264	0	2×10^{-16}	$\gamma + \gamma$
		π^+	273	+	2.55×10^{-8}	$\mu^+ + \nu_\mu$
		π^-	273	−	2.55×10^{-8}	$\mu^- + \bar{\nu}_\mu$
	K mesons	K_1^0 — K_1^0	974	0	1×10^{-10}	$\pi^+ + \pi^-$ $\pi^0 + \pi^0$
		K_2^0 — K_2^0	974	0	6×10^{-8}	$\mu^+ + \nu_\mu + \pi^-$ $\mu^- + \bar{\nu}_\mu + \pi^+$ $e^+ + \nu_e + \pi^-$ $e^- + \bar{\nu}_e + \pi^+$ $\pi^+ + \pi^- + \pi^0$ $\pi^0 + \pi^0 + \pi^0$
		K^+	966	+	1.22×10^{-8}	$\mu^+ + \nu_\mu$ $\mu^+ + \nu_\mu + \pi^0$ $e^+ + \nu_e + \pi^0$ $\pi^+ + \pi^0$ $\pi^+ + \pi^+ + \pi^-$ $\pi^0 + \pi^0 + \pi^0$
		K^-	966	−	1.22×10^{-8}	$\mu^- + \bar{\nu}_\mu$ $\mu^- + \bar{\nu}_\mu + \pi^0$ $e^- + \bar{\nu}_e + \pi^0$ $\pi^- + \pi^0$ $\pi^- + \pi^- + \pi^+$ $\pi^- + \pi^0 + \pi^0$

Family	Group	Particle - Anti-particle	Mass (m_e)	Charge	Mean life (sec)	Decay modes
Baryons	Nucleons	n	1,839	0	10^3	$p + e^- + \bar{\nu}_e$
		$\bar{n}$	1,839	0	10^3	$\bar{p} + e^+ + \nu_e$
		p	1,836	+	stable	
		$\bar{p}$	1,836	−	stable	
	Hyperons	Λ	2,183	0	2.2×10^{-10}	$p + \pi^-$ $n + \pi^0$ $p + e^- + \bar{\nu}_e$
		$\bar{\Lambda}$	2,183	0	2.2×10^{-10}	$\bar{p} + \pi^+$ $\bar{n} + \pi^0$ $\bar{p} + e^+ + \nu_e$
		Σ^0	2,332	0	$< 10^{-11}$	$\Lambda + \gamma$
		$\bar{\Sigma}^0$	2,332	0	$< 10^{-11}$	$\Lambda + \gamma$
		Σ^+	2,328	+	$.8 \times 10^{-11}$	$p + \pi^0$ $n + \pi^+$
		$\bar{\Sigma}^+$	2,328	−	8×10^{-11}	$\bar{p} + \pi^0$ $n + \pi^-$
		Σ^-	2,341	−	1.6×10^{-10}	$n + \pi^-$ $n + e^- + \bar{\nu}_e$
		$\bar{\Sigma}^+$	2,341	+	1.6×10^{-10}	$\bar{n} + \pi^+$ $\bar{n} + e^+ + \nu_e$
		Ξ^0	2,566	0	$\sim 10^{-10}$	$\Lambda + \pi^0$
		$\bar{\Xi}^0$	2,566	0	$\sim 10^{-10}$	$\Lambda + \pi^0$
		Ξ^-	2,580	−	1.3×10^{-10}	$\Lambda + \pi^-$
		$\bar{\Xi}^+$	2,580	+	1.3×10^{-10}	$\Lambda + \pi^+$

Asimov, Isaac. The Universe. New York: Walker and Company, 1967.

XVI. Particle Bombardment

A. Massless particles

1. Quantum theory--all forms of energy can be viewed as consisting of discrete little packets (quanta).
2. All particles behave in some way like waves; all waves behave in some way like particles.
3. Photons-particles of light. The rest mass is zero.
4. Gravitons and neutrinos have no rest mass and travel at the speed of light. No particle with a rest mass can travel at the speed of light.
5. The photon has a spin of ± 1; the neutrino, $\pm \frac{1}{2}$; and the graviton, ± 2.
6. The graviton has never been detected.

B. Cosmic ray sources

1. The speed of the solar wind can be as high as 450 miles/second.
2. The Van Allen belts and the magnetosphere are the same thing.
3. The ionosphere normally contains a high concentration of ions. Magnetic storms are in the ionosphere.
4. Cosmic rays may be produced by solar flares from all the stars. The ones with higher energies are those that have been "batted around" more. Also, some

stars produce rays with more energy than those produced by our sun.

XVII. Energetic Photons

A. Electromagnetic spectrum

1. The energy of visible light ranges from 1.5eV (red) to 3.0eV (violet). The greater the energy, the shorter the wave. Radio waves are 0-0.00001eV. Microwaves are 0.00001-0.001eV. Infrared rays are 0.001-1.5eV. Ultraviolet rays are 3-100eV. X-rays are 100-100,000eV. Gamma rays are 100,000+eV.

B. Antimatter

Antigalaxies emit antimatter, therefore antigalaxies may be pinpointed by the high-energy antimatter they send out.

XVIII. Radio Astronomy

A. Solar flares cause jamming of radar equipment. The flare sends out a flood of microwaves. Some are emitted by the corona, some by the surface of the sun.

B. Some planets also send out microwaves from their surfaces.

C. Microwaves are emitted from the center of the galaxy.

Gamow, George. <u>A Star Called the Sun</u>. New York: The Viking Press, 1964.

I. How Far, How Big, How Hot?

A. The surface temperature of the sun is about 5800°K, or about 5500°C.

B. Heat is produced inside the sun at the rate of 4.4 x 10^{-8} calories/second/gram material. The surface of the sun is small compared to its volume. The surface must be kept very hot to radiate all that heat.

III. The Sun's Turbulent Surface

A. The temperature of the sun increases rapidly as one goes deeper into the body.

B. The density is 1.4. The gases are highly compressed.

C. At the same density and pressure, atoms with lower ionization potentials become ionized at lower temperatures, where they are subject to more moderate collisions, than do atoms having a higher ionization potentials.

D. Most of the sun is hydrogen (82% by volume). 18% is helium. The rest are traces of other elements.

E. Sun Spots

1. The smallest ones, called pores, are just a few hundred miles in diameter. Probably smaller ones invisible to telescopes exist. Larger ones go to tens of thousands of miles. Sometimes they are

grouped together. These groups may go more than 100,000 miles. The largest group yet recorded was in April, 1947 (March 5-April 12--twice around). The total area was 6 x 10^9 square miles--more than 1% of the total apparent area of the solar disk.

2. Most sun spots occur between latitudes 5° and 30° North and South, or in the "tropical" regions. In August, 1956, there was a group of spots at 50° from the equator.

3. The sun does not rotate like a solid sphere. The rotation at the equator is faster than the rotation higher or lower. Ranges:

Distance from equator	Days rotation period
0°	24.64
15°	25.41
30°	26.45
45°	28.54
60°	30.99
75°	33.07

4. The temperature of the spots is a couple of thousand degrees lower than that of the rest of the surface.

5. The darker central part is called the umbra. The brighter ring is called the penumbra. Out from this are the outlying surfaces.

F. The sun's surface is in constant violent motion, spurting, etc. This is not just at the sun spots. This is known as granulation. Larger increases of local surface brightness are known as faculae (torches), flocculi (flakes), and flares (especially bright ones). Flares appear around sun spots.

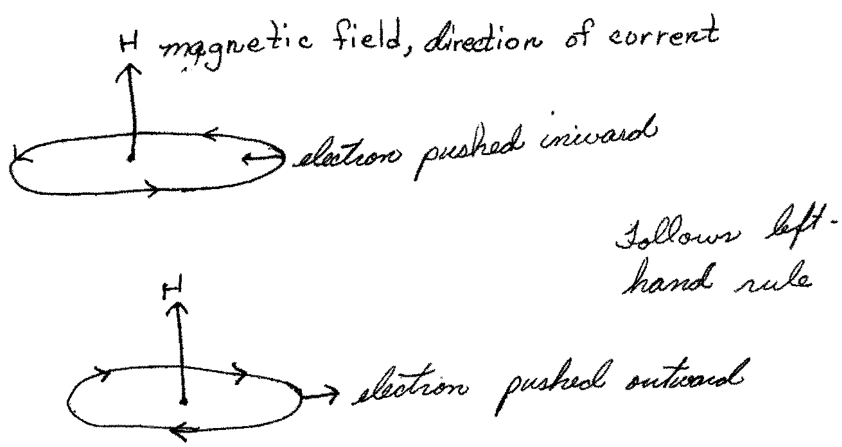
G. The Solar Corona

1. This contains highly ionized atoms common on Earth. Atoms lose electrons because of the heat.

2. The temperature of the corona is about $1,000,000^{\circ}K$. The temperature of the solar photosphere is only about $6,000^{\circ}K$. The gases of the corona are heated by the "noise" produced by the turbulent motion of the solar photosphere.

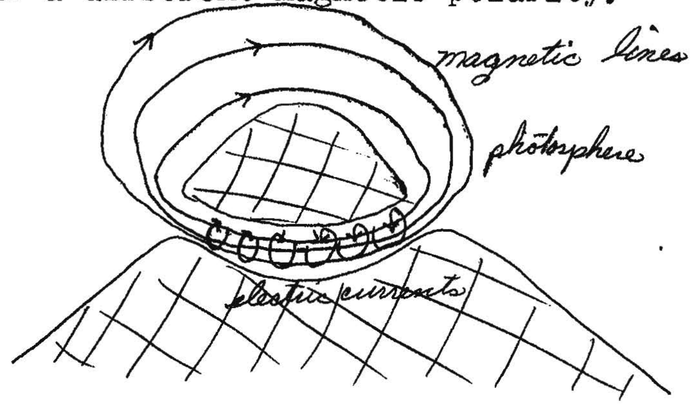
H. Solar Magnetism

1. Zeeman effect--The Fraunhofer lines in the spectrum of light emitted by the sunspots: The Dutch physicist found out that each line is split into several components located close to one another. The presence of the Zeeman effect in the line spectrum indicates that the light source is subject to the action of a magnetic field. This effect can be illustrated by a single electron turning.



There are very strong magnetic fields at the sun spots. The spots are giant electromagnets. The current feeding into them is several thousand billion amps.

2. Sun spots usually occur in pairs. Each spot in the pair has a different magnetic polarity.



There is a giant cylindrical whirl of electrically charged matter.

3. The polarity of sun spot pairs in the northern hemisphere is always opposite to the polarity of pairs in the southern hemisphere. For example, if the order in the nouthern hemisphere is south-north, the order in the southern hemisphere is north-south. This means that the whirls are in two opposite directions.

4. The polarity changes from one maxima to the next. For example, one time spectroscopic studies show the spots in the northern hemisphere to be in an arrengement of S-N. Eleven years later they are in a N-S arrangement.

5. These whirls rise and break to form flares. Electrically charged particles follow the magnetic lines of force and form the whirls.

I. Magnetohydrodynamics

The surface of the sun can be compared to cyclones on earth. The magnetism and dynamics of the sun can be basically explained with things developed on earth, such as the Tesla coil.

J. Solar activity and its influence on the Earth

1. Solar activity means the periodicity of phenomena taking place on the surface of the Sun.

2. The average period of sun spots is 11.2 years, although it has be as short as 7.5 years or as long as 16 years.

IV. The Hot Solar Interior

A. The sun is made up of plasma, the fourth state of matter. All atomic electrons are completely stripped from their normal orbits around the nuclei. Plasma can be condensed more than can regular matter. Plasma fluid density would be about 10^{14}gm/cm^{2}. However, no plasma fluid is known to exist in the universe.

B. The ideal gas law holds true for plasma.

McMahon, Allen J. Astrophysics and Space Science: An Integration of Sciences. Prentice-Hall International Series in Space Technology. Englewood Cliffs, New Jersey: Printice-Hall, Inc., 1965

I. Solar Emissions and Solar Storms

A. Introduction--The Quiet Sun

The sun exhibits a sharp disk called the photosphere. Above this is a heterogenous region not in thermodynamic equilibrium in which appear flares, prominences, spincules, etc. This is the chromosphere. Above this is the corona. Heterogenous means different in structure, quality, etc.

Bubbles of hot material in the photospheric convective zone form, rise, mix with surrounding material, and disappear. Cooler material sinks into the photosphere. The granulae appear to be visual evidence of this convective phenomena. The upper radiative zone of the photosphere is turbulent. The curl-free part of the pressure wave field formed in the granulation zone passes through the nonconvective photospheric region and enters the chromosphere. In the chromosphere the micro-turbulent part of the energy is a field of sound waves propagating in all directions. Turbulent velocity increases with height. When the material velocities of turbulance become comparable to molecular velocities, dissipation sets in. Dissipation of this energy flux causes heating of the chromosphere and corona.

As the sound pressure waves rise, they degenerate into jet-like motion which constitutes the macro-turbulent part of the sound energy and form sharp shock fronts in the higher layers. Jet-like extensions of the photosphere are called spincules.

Mechanical energy flux heats the corona. A small part is lost as X-rays. A still smaller part is lost by evaporation of particles. The bulk of the coronal absorbed energy is conducted back toward the chromosphere.

B. The Disturbed Photosphere and Chromosphere--Sunspots and Prominences

1. Sun spots

These appear generally in an eleven-year cycle.

One starts as a small round pore 1,500 to 3,000 km in diameter. A pore usually develops into numerous other spots.

One consists of a darker inner area (the umbra) and an outer area (the penumbra). Matter flows out of the penumbra. The velocity of flow increases from center to edge to about 3 km/sec. However, velocities of 6 km/sec have been observed. At altitudes of 2,000 km the flow direction reverses and is inward at 4 km/sec.

Spot groups are usually oval in shape with the long axis aleigned so that the preceding (or p) spot is closer to the equator. The higher the latitude of the group, the larger the angle of dip. For example, for spot groups at 30° to 34° latitude, the orientation is -19° from the east-west direction.

Poles. A preceding spot is one pole in one hemisphere and the other pole in the other hemisphere. A preceding spot has more flux passing through the spot area than does a following spot. The ratio is about three to one.

The temperature of the umbra is 4300-4900°K, compared to the photosphere at 5,785°K. There is a depression by about 500 km of the photosphere in the area of the spot. The magnetic field is believed to effectuate a cooling of the photosphere in the region of the spot and the depression of the region of the spot by suppressing convection in the hydrogen convection zone. This may or may not be true.

A sun spot grows to full size in a period of 10-15 days. The actual spot appears about two days after the appearance of the magnetic field. It has been calculated that if convection is halted, the time interval for the temperature to drop from 6500°K to 4500°K is only about 7.8 seconds. This indicates that the previous theory is false--or at least partly false.

One theory for sunspot coolness is that they expand adiabaticly.

2. Prominences

A full-grown prominence is a gaseous sheet about 200,000 km long, 40,000 km high, and 6,000 km thick and has a blade-like shape. It is luminous against a dark sky, but dark on the disk.

C. Solar Flares

1. A flare is a sudden and short-lived brightening of one portion of the sun. They always occur in centers of activity--that is, in regions of sun spots, facular fields, and prominences such as filaments and surges. They often appear in the regions preceding and following bimagnetic regions or in the sun-spot penumbra, but they practically never appear on top of a sun spot. They are about mid-way in a scale of violence. They have an average height of 20,000 km above the solar surface. Most light curves are asymmetric; the rising portion lasts about five to ten minutes, while the descending part lasts much longer.

2. Flare Spectra--most are obtained in the light of $H\alpha$ at $\lambda 6,563$.

3. Impulsive Phenomena in the Solar Atmosphere--Activation Theory

   Associated with a flare, a high-speed surge (active dark flocculus) may appear. Velocities attained are hundreds of kilometers per second. Surges may recur again and again. The average time between the beginning of a flare and the beginning of an accompanying surge is four minutes. Only in ten per cent of the cases does the surge appear before flare onset. The average surge starts as a bright or dark mottle 10,000 to 20,000 km in diameter and in 90% of the cases the velocity of ascent increases. The maximum velocity usually reached is above 200 km/sec and is reached in a few minutes. Then the velocity decreases. Surges may reach altitudes of 500,000 km. They do not begin precisely over the flare, but average 15,000 km from the flare.

A halo phenomena sometimes accompanies the spot.

Activation of filaments are observed as a change in darkness, size, and shape, or as internal motion. The complete dissolution of a filament may occur, but certain filaments often close to a flare may remain unchanged. Assuming that a disturbance starts at the time of the flare and in the same vicinity, a velocity of progression of 20 to 200 km/sec--the average is 60 km/sec--has been observed.

Another phenomena is that activations and surface changes are propagated at velocities of 500 to 1500 km/sec. Some flares appear to exhibit an explosive phase during rise to maximum brightness. Such an explosive phase is often associated with a sudden expansion of the flare border. During the explosive phase of some flares, what appears to be diffuse faint clouds, showing as slightly brighter or slightly darker than the background surrounding the flare, are ejected from the flare at high speeds. At a great distance from the source, abrupt appearance and disappearance of the filament occurs.

4. X-rays and Ultraviolet rays. X-ray emission starts with the visible flare and ends with the decay of the flare.
5. Other Phenomena. Cosmic rays, clouds of solar plasma, and a variety of radio emissions.
6. Cosmic Rays

   The solar cosmic rays are generally believed to originate after the beginning of the flare. They are believed to be generated in the hot overlying coronal regions above a flare. There is a slowly decaying tail for the intensity curve, lasting several hours after the end of the flare.
7. Cosmic Radio Background Decreases

   Shortly after the beginning of a flare in August, 1958, a decrease was observed in the cosmic radio noise (observed by raometers--relative ionospheric opacity meters). Four hours later a further decrease occurred. This noise remained at a low level for many days after the flare. The ionizing effect of these particles are limited to the polar caps, but the transit times imply that the particles are very energetic and of low cosmic ray energy. A "corpuscular E" layer is formed in the ionosphere at about 100 km altitude. To maintain the observed ionization, about 10^{10} ionizations / cm^2-sec are required. If every incoming proton generates 10^4 pairs, an intensity at the pole of 10^6 protons/cm^2-sec is sufficient.

8. Other stars have flares, also.

9. Flare Theory

The theory that flares represent electrical discharge must be unacceptable on the basis that the induced currents would effectively oppose the build-up of discharge currents. Also, the accelerating layer would be very thin (about five meters). The densities and temperatures implied by a thermonuclear reaction, which would need to be sustained for tens of minutes, together with the absence of neutrons, make the thermonuclear reaction postulate very unattractive.

Gold and Hoyle theory (1960): Consider a filament which consists of a bundle of lines of force which emerges from one point in the photosphere and reenters at another point. This is in the subphotosphere and of energy 10^5 ergs/cm^3. The points of emergence and reentry are subject to twisting. Total energy is about 10^{30} ergs. Internal solar magnetic fields become untwisted by the flare.

D. Solar Radio Emissions--The corona

X-ray emission and slowly varying 10 to 15 cm radio emission are associated with greater-than-normal coronal densities.

1. Nonthermal Bursts--associated with flares
   a. Type III burst--lasts less than 10 seconds. Mainly polarized. Associated with the first phase of the flare. The speed through the corona is 10^5 km/sec. The greater the flare area, the greater the correlation.
   b. Type II--This is rarer than the Type III. There is an average delay of seven minutes between the flare and the burst. It lasts 10^2 to 10^3 seconds. It travels about 10^3 km/sec. This accounts for the seven minutes.
   c. Type IV--lasts 10^4 seconds. About 90% are preceded by the flare. 100% polarized.
   d. U-type--lasts 3-10 seconds. About 80% are associated with flares. The speed is 10^5 km/sec.
   e. Type I--occurs in noise storms. The individual pips last less than a second, but the noise storm can last for an hour or for days. It is mainly polarized.
   f. Type IV--lasts 10^2 seconds. Often associated with flares.

2. A permanent, thermal radio radiation is emitted from the quiet sun.
3. Thermal radiation is emitted from the centers of activity.

Brandt, John C. and Paul W. Hodge. Solar System Astrophysics. New York: McGraw Hill, 1964.

III. Basic solar data and the solar interior

Studying the sun allows us to speculate about other stars.

A. Data

1. The rotational velocity is about 250 km/sec.
2. Perpendicular motion is 20 km/sec.
3. The mass ($M_{\odot}$) is 1.99×10^{33} grams. $M_{\odot}$ is often used as a basic unit.
4. The escape velocity for a neutral particle is 617 km/sec.
5. The distance from the earth to the sun is 1.493×10^{13} cm.
6. The mean angular diameter is 31'59".
7. The radius ($R_{\odot}$) is 6.96×10^{10} cm. $R_{\odot}$ is often used as a unit for distance.
8. The sun is perfectly spherical shaped.
9. The energy given off is 1.95 cal/cm^{2}min. This is equal to 3.9×10^{53} ergs/sec.
10. The temperature is 5750°K.

B. Theory of the Formation of the Sun

There was a condensation of interstellar gas and hydrogen. All the elements were made in the stars with hydrogen as the starting material.

C. The Solar Interior

The solar material is opaque to all usable wavelengths only a short distance below its relatively cool outer layers. Therefore, it is impossible to obtain any information directly about the interior of the sun. All the ideas are theory derived from surface information.

IV. Radiative Transfer and the Photosphere

A. The photosphere comprises the portion of the solar atmosphere from which we receive the major portion of the sun's optical radiation. It is in radiative equilibrium.

B. The Solar Photosphere

Widt, in 1939, suggested that the opacity of the sun was due to bound-free absorption of the negative hydrogen ion.

Layer	Height (km)	Main Energy Transfer
corona	20,000 - 1.400,000	thermal conduction
transition layer	3,000 - 20,000	mechanical energy
chromosphere	0 - 3,000	radiation
photosphere	-270 - 0	radiation
hydrogen convection zone	-140,000 - -250	convection and radiation

Note: The height is given in terms of kilometers above the photosphere.

C. Thermodynamic Considerations

There are fluctuations of density and temperature in the photosphere. The most important of these are solar granulation and related phenomena.

V. The Hydrogen Convection Zone, Chromosphere, and Corona

A. A minute part of the solar energy flux in transported through the photosphere in the form of mechanical energy. This fact greatly alters the physical situation in the outer solar atmosphere. The deposition of mechanical energy causes the temperature to decrease a few thousand degrees Kelvin, then increase rapidly to values of about 10^{6} °K. This energy is related to the solar granulation and is probably produced in the hydrogen convection zone.

B. The Hydrogen Convection Zone and Noise Generation

1. There is no satisfactory theory of the physical processes occurring in the convective zone beneath the photosphere.
2. The hydrogen convection zone exists in its present location for two reasons:
   a) The adiabatic gradient decreases because of the hydrogen ionization.
   b) The structural gradient increases because of an initial increase in the opacity. The increase in opacity reduces the "mixing" of photons and allows the existence of the large temperature gradient responsible for the convection.

3. Granulation. This provides a fairly direct link between the observations and the theory of the convective zone. The mean diameter of the granules is about 700 km. The mean half life is about four minutes. The root-mean-square temperature fluctuation is about 100°K. This does not conflict with the somewhat larger temperature fluctuations considered in the nonhomogenous models because the fluctuations of a scale smaller than the resolution of the instrument (about 300 km) are not included. The granulation is independent of the heliocentric latitude and of the solar cycle. Therefore, it appears to be independent of solar activity, and it is a basic solar process. It is obscured near the limb by the increase in the slant optical thickness of the photosphere.

4. Noise generations and atmospheric heating. The turbulent subphotospheric motions appear to be the source of mechanical energy for the chromosphere and the corona. The hydrogen convection zone also has turbulent motions. Almost all the energy in generated in a layer about 100 km thick. This energy goes into acoustic waves that travel at the speed of sound.

C. The Chromosphere

1. Data

a) It is 10,000 to 15,000 km thick.

b) It is poorly understood.

c) It is very inhomogeneous.

d) It is not in thermodynamic equilibrium, particularly above 5,000 km.

e) Lines of CN, as well as those of hydrogen, helium, and the usual metals, are observed in the lower chromosphere. Fe XI is observed in much of the chromosphere.

3. Three regions:

a) First 500 km. This is mainly an extension of the photosphere. Height = 0 is defined as the visible edge of the sun.

b) Lower chromosphere. The height is up to 5,000 km. It is composed mostly of neutral hydrogen. The temperature is about 5000^{o}K.

c) Upper chromosphere. This is mostly ionized. The height is between 5000 km and the coronal value.

4. During the quiet sun brilliant streamers, called spincules, emerge from the lower chromosphere. They appear to be aleigned with the solar magnetic field. They are carried upward by the slow mode waves mentioned in B. They could possibly carry energy to the corona.

D. The Corona

1. This is the portion of the solar atmosphere above 1.03 $R_\odot$.

2. Three arbitrary divisions of the corona:

   a) Inner corona ($1.03 < r/R_\odot < 1.3$)

   b) Medium corona ($1.3 < r/R_\odot < 2.5$)

   c) Outer corona ($r > 2.5R_\odot$) or interplanetary medium.

3. The light of the corona has three components:

   a) K corona--a continuum due to electron scattering.

   b) F corona--inner zodical light. This is solar radiation diffracted by interplanetary dust. The radiation is not physically connected with the corona.

   c) E corona--emission corona. This is the total light of the coronal emission lines.

4. A streamer is a long extension of the corona. Subdivisions:

   a) Fans. These have dimensions of about 1 $R_\odot$ or greater. They determine the general form of the corona at any given time.

   b) Rays. These are narrow streamers besides the fan rays. Polar rays and rays above the faculae are in this category.

5. The wavelengths of the lines in the emission corona do not coincide with the wavelengths of the

Fraunhofer lines. They come from highly ionized atoms.

6. Radio emission from the corona is mainly thermal in origin.

VI. The Solar Magnetic Field and Solar Activity

A. Introduction

1. Magnetic fields are important in the transfer of energy from the hydrogen convection zone to the solar envelope. They influence the structure of the corona. Mostly, however, they cause solar activity--mainly sun spots.

2. Flares cause radio communication fade-out and auroras.

3. Page 122, T. G. Cowling, "Solar hydromagnetics is a fascinating subject and one which is very imperfectly understood; but it is also one in which the probability of being led astray by seductive theories is very high."

B. Basic Hydromagnetics

1. The solar atmosphere is essentially electrically neutral.

2. There are three elementary types of waves or oscillations which can exist in a plasma.

a) Electromagnetic waves. These are physically the same as ordinary waves in a vacuum.

b) Plasma oscillations. These result from an electrostatic restoring force.

c) Hydromagnetic waves.

C. The General Magnetic Field

1. Theories of the origin and maintenance:

a) It is essentially a fossil--a natural product of the sun's process of formation.

b) The origin is due to the motion of electric charges due to solar rotation. This is probably too small to count.

c) Thermal and pressure theories. Gradients of the electron pressure and the solar rotation can produce currents flowing in meridianal planes which, in turn, produce an azimuthal magnetic field. However, the solar field is thought to be poloidal. It is more difficult to produce a poloidal field, and pressure theories are probably inadequate.

d) Dynamo theories. The motion of solar material across the lines of force of an existing field produces currents, and these currents are thought to maintain the field. It has not been possible to disprove the dynamo mechanism, but attempts to establish them have not been seccessful.

e) Turbulent magnetic fields. The interaction of turbulent motions with the field can produce a turbulent magnetic field by a process roughly analogous to equipartition. The result of such a mechanism is to build up an irregular, small-scale field which probably cannot be identified with the general solar field.

2. The general field reverses polarity with the same period as the solar cycle.

D. Sunspots

1. These are dark markings on the sun composed of dark centers (umbrae) and border regions (penumbrae). The umbra is rather structureless, but granulation has been found in it. The penumbra consists of a group of small filaments radially oriented with respect to the center of the umbra. The ratio of the diameter of the penumbra to that of the umbra is about 2.4. This is lower for very large spots and greater for very small spots. The diameter of a spot ranges from several thousand to several tens of thousand kilometers. Some spots have a bright ring around the penumbra 2-3% brighter than the photosphere. The upper surface of the spot is a shallow depressed area. A large spot group can attain lengths of over 100,000 km.

2. First a small spot, or pore, appears between the

granules. Other pores appear, and a young spot group develops. It may disappear after a few hours, or it may "grow" into a large group.

3. Wolf's relative sunspot number:

$$R=k(10g+f)$$

R=number of spots visible on the solar surface
f=number of individual sunspots
g=number of groups
k=observational bias

4. Solar rotation takes 27 days. Therefore, the spots change every 27 days. At sunspot maximum there are ten or more groups on the disk. The cycle is not always the same, but usually there are 6.7 years from maximum to minimum and 4.6 years from minimum to maximum. The average cycle is 11.2 years.

5. Approximate number of sunspots in given years: A chart is given on page 140. Generally, there were an exceptionally high number of spots in 1727, 1738, 1778, 1837, 1870, 1947, and 1957. There an exceptionally low number of spots in 1700, 1710-1711, 1723, 1733, 1744, from 1790 to 1834, and from 1873 to 1914.

6. Almost all spots are around two zones at 45° latitude above and below the equator. The zones are 15 to 20° wide. Spots do not move. The sun

rotates. They seem to last about one month. Spots first appear at $\pm 30^\circ$ latitude. They appear up (down) to $\pm 15^\circ$ by solar maximum. The last spots of the cycle may be as low (high) as $\pm 8^\circ$. The migration of the sunspot zone is Aporer's law. This is shown in a Maunder butterfly diagram on page 141.

7. Hale in 1908 discovered that sun spots contain magnetic fields ranging in strength from several hundred to several thousand gauss. The maximum field strength is fairly constant until the spot is about to disappear. Thus, it appears that the field seems to decay by the progressive sinking or rising of the outer lines of force into the photosphere, or the corona. This rules out decay by diffusion. Also ruling out diffusion is the fact that decay by diffusion would take 1000 years. A spot appears because a subsurface field is occasionally brought up to the surface and it disappears either by sinking back into the subsurface layers or by expanding outward into the corona.
8. The temperature of the umbra is about $4600^\circ K$.
9. The surface gravity of a sunspot is the same as that of the sun.
10. There is a general, horizontal radial outflow

from sunspots with speeds of about two km/sec. This is called the Evershed effect. The flow is not entirely radial because of the Coriolis force. This is not well understood.

11. Classification of spot groups:

   a) Unipolar groups. α. These are single spots or groups of spots with the same magnetic polarity.

   b) Bipolar groups. β. The preceding (p) and the following (f) spots, in the solar rotation, are of opposite polarity.

   c) Complex groups. γ. These have many spots of both polarities but cannot legitimately be classified as β groups.

12. About 90% of the spots are of class β, 10% α, and 1% γ. The unipolar groups are usually the remaining p spot of an old bipolar group. Often the distribution of faculae around a unipolar spot or group resembles the distribution of faculae around a bipolar group. In this latter case, a magnetic region is found in the expected position of the "missing" spot. The magnetic field is present, but no spot develops. It can be taken from this that the spots are only a byproduct of a more important aspect of solar activity. This may be faculae. Faculae appear before the sun spots and outlast them by several solar rotations.

13. The magnetic flux in the p spots is about three times that in the f spots. Also, the p spots are somewhat larger and longer-lived than f spots. The bipolar magnetic region (BMR) is the basis for the development of sunspot groups. The BMR's follow the law of polarity better than do spots, and equal amounts of magnetic flux of opposite polarity are present in the p and f portions of the BMR.

14. Sunspot theory by H. W. Babcock: The general type of field is a dipole field near the polar caps, but away from the caps it lies in a thin surface layer about $0.1R_{\odot}$ thick. This field is considered as frozen-in to the solar material. The field lines are carried along by solar rotation and drawn out by differential solar rotation. The result is an amplification of the field. This amplification depends on the latitude. A field of about 250 gauss (the critical value) will produce "magnetic buoyancy" when amplified to 10^3 gauss by the twisting into flux ropes by distortions in the surfaces of constant angular velocity caused by convection. The ropes are unstable, and they form a loop. Loops which stick up through the surface are the mechanism for the production of BMR's. Loops can also arise from magnetic

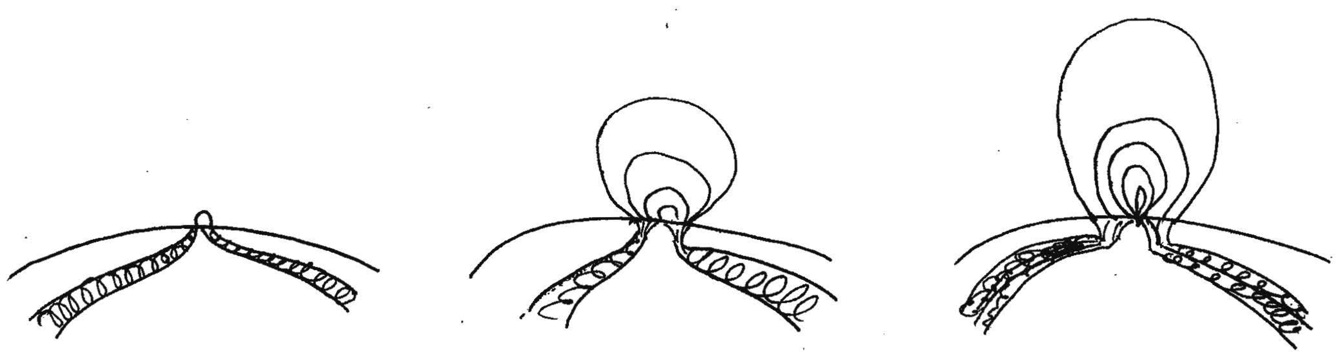
buoyancy in regions where the field is large. The density of a loop is less than that of a magnetic region. Therefore, the region will have an upward buoyant force. Expanding lines of force from BMR's move outward toward the general dipole field. Severing and reconnection occur. With each process, a portion of the general field is neutralized. Finally a new general field of reversed sign is formed.

15. There are some difficulties in this theory, but it is the best so far. Summary:

a) At first the BMR is compact, but it soon expands into the corona.

b) A submerged flux rope is developed because of the differential solar rotation. This results in higher field strengths in the p part of the BMR.

c) The expansion continues, the field strength decreases, and the signs of solar activity gradually disappear.



E. Faculae

1. Terminology

Faculae used to mean the bright regions seen in white light near the limb of the sun. Now these are called photospheric faculae. Bright areas observed in K line or $H\alpha$ spectroheliograms are called chromospheric faculae or plages faculaires or plages. A flocculus is a small, bright (but sometimes dark) area associated with chromospheric faculae. Chromospheric faculae are the same thing as bright focculi. The physical entity responsible for these various manifestations is called a facula. It can be subdivided into photospheric and chromospheric. A small bright or dark area in a facula is called a flocculus.

2. Structure and relation to other phenomena

a) Sunspots are always accompanied by faculae, but faculae can occur without sunspots. Faculae appear before the sunspots and usually last for several solar rotations after the spots disappear. The latitude distribution of faculae is a broader belt than is that of spots.

b) Faculae are closely related to magnetic fields. Polar faculae exist. This may be because of the general solar field or the polar field suggested by the polar, coronal rays.

c) Faculae can be observed only near the limb in white light. They cannot be distinguished from the photospheric background at the center of the disk. This means:

1) They are brighter than their surroundings in their upper portions.
2) They are cooler than their surroundings in their lower portions.
3) They are not in radiative equilibrium.

d) Chromospheric faculae are generally larger than photospheric faculae.

e) Basicly, faculae seem to be composed of a network of coarse mottles, which are composed of facular granules. These structures also exist in the quiet chromosphere. The main difference between the quiet chromosphere and the facular regions appears to be that the facular region has a higher density of the bright elements (granules or mottles) found in the normal chromosphere. At first the bright, fine mottles are in a compact structure. This gradually disperses. The facular areas become patchy and eventually gradually merge into the normal chromospheric network.

3. Theory

Faculae occur because of an intensification or amplification of the process which normally heats the chromosphere.

F. Flares

1. Basic data

a) A flare is a short-lived sudden burst of light in the vicinity of a sun spot. They usually occur near γ or multipolar groups, often when a change in the structure is occurring. They are correlated with disturbances in the ionosphere and the magnetic field of the earth. This is probably through the emission of corpuscular radiation. Such activity can then produce auroras and the interruption of radio communication. Flases are associated with the emission of radio waves, ultraviolent radiation, X-rays, and cosmic rays. This basic process has been observed in other stars.

b) Sunspot number divided by 25 gives the approximate number of flares per day. Flares are classified according to area and brightness, and In order of increasing importance, the classifications are 1^-, 1, 2, 3, 3^+. Flares of class 3 and especially 3^+ are generally responsible for terrestrial effects. A 3^+ flare lasts about three hours. A 1 flare lasts about twenty minutes.

c) Development: There is a rapid rise to peak intensity, which is followed by a frief period of maximum brightness. Then there is a slow return to the preflare brightness.

d) Flares leave the chromospheric structure essentially unchanged. A typical flare has an area of about 10^{19} cm^2. He^3 is produced in flares. Particles of high energy are envolved. Energy output is as high as 10^{27} ergs/sec for 10^3 sec. This is equal to 10^{30} ergs.

2. Màss motions and related effects

a) Flare surges occurring on the limb are called surge prominences. Particle speeds up to 500 km/sec are reached. Heights up to 100,000 km are reached. The probability of flare surges increases with the importance of the flare.

b) Both filaments and surge prominences are influenced by the same force field--probably magnetic. A flare can have an effect on nearby filaments.

c) Flare puffs are a very rapid expansion of a flare nearly at onset. Flare surges can occur at any time during the life of the flare.

Speeds found in puffs are as high as 10^3 km/sec.

3. Theory

The flare is of magnetic origin. One theory is the discharge ina neutral plane. The other is twisted loopsof magnetic flux.

G. Prominences

1. General description. On the limb they are bright, arch-like structures resting on the chromosphere but extending into the corona. Against the disk they are dark filaments. They exist in a large variety of forms.

2. Quiescent and related prominences

About one third of the quiescent prominences are associated with spot groups. They generally form on the polar side of the group, usually with the filament pointing toward the preceding spot. They appear about one solar rotation after the first spots form. The rest of the quiescent prominences form in the general area of plot groups. They avoid direct association with the spots. However, all the quiescent prominences are about the same.

3. Sunspot prominences.

a) There are two types: the arch or loop type and the condensation or know type.

b) Downward motions predominate. They are in constant motion. The spot prominences correspond to the unstable filaments found in spot groups. In the loop type the trajectories can usually be explained as motion along the lines of force of a dipole situated just below the surface. The energy of the magnetic field in these prominences greatly exceeds that in thermal or random motions. In the quiescent prominences the two energy densities are of the same order of magnitude. The mean projected length is about 60,000 km.

c) Condensation or know prominences consist of a series of bright structures. The length is 50,000 to 100,000 km above the surface. They are connected to the chromosphere. Material apparently condenses into the knots and then flows downward and into the chromosphere. These prominences are associated with flare activity and with coronal condensations.

d) General mechanism is probably the same as for the quiescent, except that they are not mechanically supported. They are maintained by a balance between the rate of the condensation of material from the corona and the rate of flow along the field lines into the chromosphere.

H. Center of Activity (CA)

1 day--facular speck formed. Elongated in east-west direction.

2 days--first spot formed at west end. Facula very bright close to spot.

5 days--second spot formed in east region. Numerous small spots between p and f spots. Flares. Filaments appear. Brightness of facula keeps on increasing. Chromospheric ejections. Spot prominences.

11 days--large penumbrae. Flare activity and facular size and brightness increasing.

27 days--nearly all spots except p spot disappeared. Few flares. Size of facular region increasing. Filament stable.

54 days--all spots gone. Facular region increasing in brightness. Cut in half by filament, which has grown.

81 days--facular region dissolves. Filament growing.

108 days--facula completely dissolved. Filament reached maximum length. Horizontal with equator.

135 days--filament decreased.

162-270 days--things going back to normal.

The magnetic field is first observed a day or two before the first spots or faculae. Maximum flux is reached at 27 days--one rotation.

VII. The Solar Spectrum

A. Gamma Rays and X-rays

The Quiet Sun does not produce gamma rays. Flares and other high-energy events do, however. The same is true for X-rays. These come from the corona and transition regions.

B. Extreme and Far-Ultraviolent Radiation

Between 100 and 3,000 A is this range. It comes from the lower chromosphere and the photosphere. It is produced during the Quiet Sun. Variation through the solar cycle is possible, however.

C. Lyman-α

The Lyman-α line is the dominant feature of the solar extreme ultraviolet spectrum. Radiation is not enhanced in flares. It is about constant, but there is some radiation. The flux is 6 ergs/cm^{2}sec. It comes from regions associated with solar flares.

D. Optical radiation carries the bulk of the solar energy.

E. Radio waves are 8mm to 15 m. These waves correspond to solar activity.

F. High-energy electrons are formed between the two loops. So are radio bursts.

VIII. The Interplanetary Gas

A. Introduction

a) This is a constant flow of material from the sun. It is called solar corpuscular radiation or solar wind. The interplanetary medium is considered.

as an extension of the solar corona.

2. Three components of interplanetary gas (plasma):

   a) Flare-associated events.

   b) Apparently discrete streams with a 27-day period. These are thought to be associated with unipolar regions on the sun. The streams may be the extension of large coronal streamers.

   c) General, steady, wind-like expansion.

B. Theoretical Models

1. The gas is assumed to be spherically symmetric and in a steady state. The net flow of energy into a volume (from the divergence of the conductive energy flux, for instance) must go into the work involved in expanding gas or into the internal energy of the gas by raising the temperature.

2. Parker's theory. The corona is held at some constant temperature out to a certain point. Beyond that point the corona expands adiabatically. This is probably on the right track.

   adiabatic expansion $dQ = 0$ Then $dU = -dW$ so either $dW = 0$ and $dU = 0$ or else $dW > 0$ and $dU < 0$. neither agrees with experiment?

3. Chamberlain's theory. Energy is supplied only at the base of the coronal. This gives a smaller speed for the particles than does Parker's theory.

C. Empirical Results and Models

1. Zodiacal light is (not) caused mainly by scattering due to electrons. Some fluctuations in zodiacal light is due to electrons in a corpuscular stream.
2. There is a cutoff of the geomagnetic field at about $14R_o$.

D. Space Probe Results

The solar wind increases during solar activity. It is composed mainly of helium and protons. The interplanetary field varies between 2 and 10 . It is predominantly radial, but a definite transverse component exists.

E. Neutrals in the Interplanetary Gas

The stage of ionization of elements in the interplanetary medium just outside the earth is the same as that in the corona. Therefore, the interplanetary medium is a plasma.

F. Cosmic Rays and the Interplanetary Magnetic Field

1. Primary particles of the energy range 10^9-10^{10}eV are produced in solar events associated with flares. The first particles of an event come straight from the direction of the sun. This means that they are not appreciably deviated by the interplanetary magnetic field. There are disordered magnetic fields outside the earth's orbit which can scatter the rays.

2. The field is affected by solar rotation. This accounts for an east-west effect. Flares on the western limb of the sun produce more observable cosmic-ray events on the earth than do flares on the eastern limb. "When the sunspot number is greatest, the intensity of cosmic rays is the least, and vice versa." (I question this.) This is in the ionization chambers. This is closely related to the charges in the interplanetary magnetic field caused by solar activity. It is caused by the change in primary rays. ??

3. The region of disordered fields is thicker and more disordered during sunspot maximum. A galactic particle will have a harder time getting through.

4. The Forbush decrease is a decrease in secondary-neutron or μ-meson intensity due to a sudden 30-40% decrease in the intensity of the primary beam. These events occur about one day after some large solar flares. The earth is shielded from galactic cosmic rays. This could be the explaination for the statement in 2. The decrease is not in all cosmic rays, but only in galactic cosmic rays.

IX. Comets. The study of their tails lead to the concept of the solar wind.

X. Meteors send out radio signals.

XI. Meteorites

A. These provide a good method for learning about the rest of the universe.

B. The bombardment of meteorites by cosmic rays produce radioactive materials.

XIII. Interplanetary Dust

Zodiacal light is observed as a faint band of light oriented along the ecliptic and increasing in intensity toward the sun. It is observed only on a very dark night. It gives some insight into interplanetary medium and dust. It is the scattering of sunlight. The particles are of the order of 10μ.

XVIII. Atmospheres of the Terrestrial Planets

A. Whistlers are radio waves produced by lightning.

B. The Van Allen belts are two zones of radiation surrounding the earth. They are made up of charged particles--electrons and protons--trapped in the earth's magnetic field. Theories of the origin of Van Allen particles:

1. They ~~are ejected~~ directly from the solar wind or plasma clouds.
2. They are accelerated locally in the geomagnetic field.
3. They arise from β decay of neutrons. This would come from collisions of cosmic rays with atmospheric nuclei.

C. Large magnetic storms are associated with solar flares.

D. It is a mystery exactly what causes auroras. ~~It~~ They could be caused by particles from the Van Allen belt. Or ~~it~~ they could be caused by plasma instability.

E. Airglow is light in the night sky. It probably comes from excitation by chemical reactions and recombination.

Bonestell, Chesley and Willy Ley. Beyond the Solar System. New York: The Viking Press, 1964.

I. Voyage to Alpha Centauri

A. The path of the earth is like that of a spring. This is because of the motion of the sun.

B. The planets farther away from the sun than Mars, except Pluto, seem to consist mainly of hydrogen gas. These are called the outer planets or the gas giants. Mercury, Venus, Earth, and Mars are called the inner planets. They are smaller. Between Mars and Jupiter are 35,000 planetoids or asteroids. The largest, Ceres, has a diameter of 480 miles.

C. In one-sixth of its orbit, Pluto is closer to the sun than is Neptune. It was probably once a moon of Neptune.

D. The planets and the sun are probably the same age.

E. Nebula is Latin for "fog". It is a huge cloud of gas, mostly hydrogen, and cosmic dust. This could have condensed to form the stars and planets.

F. Kepler's Third Law: "The relationship of the squares of the orbital periods of two planets is the same as the relationship of the cubes of their mean distances from the sun." page 11.

G. The Crab Nebula is the remains of a supernova explosion observed and recorded in 1054 by Chinese astronomers. The Horsehead Nebula is in the constellation Orion. So is the Great Nebula, which has some very hot stars within it.

II. Names and Shapes in the Sky

A. The red shift is produced by a receding star. Every line is displaced a little bit toward the red end of the spectrum.

B. The blue shift, a shift toward the blue-violet, is produced by an approaching star.

Blanco, V. M. and S. W. McCuskey. <u>Basic Physics of the Solar System</u>. Addison-Wesley Series in the Engineering Sciences. Reading, Mass.: Addison-Wesley Publishing Co., Inc., 1961. Chapter 6

I. The Sun

A. Structure of the Outer Layers

The atmosphere of the sun consists almost entirely of hydrogen. About 10,000 as many hydrogen atoms as any other atoms exist there. Heavier atoms are ionized by heat. Heat does not ionize hydrogen atoms, but electrons may attach to them. The negative hydrogen atoms cause opacity.

B. Phenomena in the Outer Layers

1. The inner atmosphere is the photosphere; the outer atmosphere is the chromosphere and the corona.
2. The chromosphere is the region responsible for the emission spectrum that is observed during a solar eclipse after the light from the photosphere has been blocked out by the moon. The lower part of the chromosphere is sometimes called the reversing layer. The radiation from the deeper layers undergoes most of atomic and molecular absorption seen in the spectrum of the solar disk.
3. The shape of the corona varies much during the solar cycle: circular during minimum and elongated along the sun's equator during maximum.

4. Phenomena in the Quiet Sun

a) Granulation. This is a mottled grainlike structure in the photosphere. They are bright patches of irregular shape. The average diameter is 700 km. The average lifetime is a few minutes. They are produced by turbulence in the photosphere.

b) Spicules. These are spikelike bright projections seen on the limb of the sun. The lifetime is a few minutes.

c) Absorption lines. Absorption line intensity is measured as a function of the wavelength across a line.

5. Phenomena in the Active Sun

a) Sunspots. The diameter of the umbra is up to 75,000 km. The penumbra is about twice as large. The Wilson effect is that spots observed close to the limb of the sun show as asymmetry between the umbra and the penumbra. This indicates that the spot is a depression in which the inward-sloping sides form the penumbra. One cannot predict from one cycle to the next the number of sun spots. "There is evidence that an 80-year cycle is superposed on the 11-year one. The intensity of light from the umbra is about one fourth that from the photosphere. Magnetic fields much stronger than the general field are present in spots. Intensity varies with the size of the spot. It is about 100-4000 gauss. The lines of force are vertical in the center and nearly horizontal at the elge. The field-intensity distribution is regular, even though the spot is irregular in shape. The Evershed effect is that there exists an outward flow of mass from the umbra.

b) Faculae. These are areas surrounding the sunspots that are lighter than the rest of the photosphere.

c) Flares. These occur unexpectedly. They last about two hours. The occurence is correlated with intensification of cosmic rays.

d) Filaments. These are ribonlike dark markings found near groups. Viewed against the solar limb, they are called prominences.

B. Solar-terrestrial relationships

1. Magnetic storms are sudden violent disturbances. They cover the entire earth. They begin within one or two minutes.

2. Auroras appear in auroral zones 23° from the geomagnetic pole. They are caused by the bombardment of the earth's atmosphere by electrically charged particles. The magnetic field of the earth deflects these particles and guides them to the auroral zones. Some problems are not explained, but the basic principle is well understood.

Does this harmonize with page 67 statements

3. Magnetic storms tend to occur about one day after an intense flare in the inner seven tenths of the sun's disk. There are frequent exceptions.

4. A crochet is a magnetic field disturbance consisting of small displacements. They are sudden and about thirty minutes long. They are confined to the sunlit side of the earth. They occur synchronously with class 3 and 3^{+} solar flares. They are caused by electromagnetic radiation from flares.

5. Low-energy cosmic radiation intensity increases after an intense flare. They leave the sun at speeds close to that of light.

C. Interplanetary Dust and Gas

1. Whistlers are sounds of decreasing pitch that can be heard by a radio receiver tuned to low frequences.

2. The material in the corona is plasma, or ionized gas. It therefore carries with it the lines of force of the general magnetic field of the sun.

Leprime-Ringuet, Louis. Cosmic Rays. New York: Printice-Hall, 1950.

I. Fundamental Concepts of Corpuscular Physics

A. Cosmic rays have high frequency, low intensity, and high velocity.

B. A very high-velocity electron produces in air, at normal temperature and pressure, fifty ion pairs of primary ionization per centimeter. The total ionization is about 80. The ionization of a particle is proportional to its velocity. An atomic nucleus in rapid motion liberates many more ions than an eledtron does.

C. The photoelectric effect is the emission of electrons by matter. It depends only on the frequency of the exciting radiation, not on the intensity. Ways of measuring the energy of the electrons:

1. Through the action of an electrostatic field of suitable direction, which stops the electrons.
2. Through observation of electron trajectories in a cloud chamber.
3. By measuring the radii of curvature of the electrons' paths in a magnetic field, a photoelectric plate being the donor. Electrons thus emitted are called photoelectrons.

D. Compton effect. A photon interacts with an electron. The photon is scattered with a loss of energy. An electron is set in motion.

II. Restricted Relativity--Mass as a Function of Velocity

$$m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$ m_0= rest mass

The mass of a cosmic ray can be figured in this way.

III. Methods of Corpuscular Physics Adapted to Cosmic Radiation

Photographic-emulsion method. A photographic plate covered with a thick emulsion of silver bromide is sent up, for all practical purposes, above the earth's atmosphere. When a particle comes in contact with the plate, it alters the grains of AgBr that it touches. When the plate has been processed one can see a discontinuous trail of these grains. These trails show the paths of the particles. From these paths the size, charge, and speed of the particle can be determined.

Weast, Robert C. Handbook of Chemistry and Physics. Forty-seventh Edition. Section F. Cleveland, Ohio: The Chemical Rubber Co., 1966.

Cosmic rays "Highly penetrating radiations which strike the earth, assumed to originate in interstellar space. They are classed as: primary, coming from the assumed source, and secondary, those induced in upper atmospheric nuclei by collision with primary cosmic rays."

Photon "A photon, or gamma ray, is a quantum of electromagnetic radiation which has zero rest mass and an energy of h (Planck's constant) times the frequency of the radiation. Photons are generated in collisions between nuclei or electrons and in any other process in which an electrically charged particle changes its momentum. Conversely photons can be absorbed (ie. annihilated) by any charged particle.

Planck's constant "Relates the energy of a quantum of radiation to the frequency of the oscullator which emitted it. It has the dimentions of action (energy x time). Expressed by $E = h\nu$ where E is the energy of the quantum and ν is its frequency. Its numerical value is $(6.62517 = 0.00023) \times 10^{-27}$ erg sec."

Bulletin of the American Physical Society. Series II, Volume 13, Number 11. November, 1968.

Page 1397-BJ2
Solar Activity and the 11-year Modulation of Cosmic Rays. V. K. Balasubrahmanyan.

The 18th solar cycle (1944-1954) has two prominent and widely separated cosmic-ray minima corresponding in phase with the two maxima. For the 19th solar cycle the existence of two minima is less prominent than for the 18th solar cycle. The maximum at higher solar latitudes is more effective in reducing cosmic-ray intensity than is the maximum at lower latitudes.

Page 1399-BJ12
Satellite Observations of Short-Lived Low-Energy Particle Increases Associated with Magnetic Storm Sudden Commencements. R. A. R. Palmeira, F. R. Allum, K. G. M. Cracken, and U. R. Rao.

The Center's cosmic-ray anistoropy detector on board the IMP-F satellite has detected six cases of short-lived, low-energy particle increases in close time association with the occurence of magnetic storm sudden commencements. Examination of all sudden commencements reported by more than five stations from May, 1967, to April, 1968, has revealed:

a) Almost in every case in which there was a solar flare increase preceding the sudden commencement, and the cosmic-ray intensity was still high at the time of the sudden commencements, the short-lived cosmic-ray increase was observed.

b) In every case in which the cosmic-ray intensity was back to normal at the time of the sudden commencement, the short-lived increase was not observed.

c) All observed increases ovvurred within a few minutes from the sudden commencement, lasted less than an hour, and were restricted to less than 10-MeV particles.

Page 1411-CG10

Observations of Van Allen Belt Protons in Nuclear Emulsions 1961-1968. Robert C. Filz and Ernest Holeman.

The time behavior of 55-MeV trapped protons was determined from measurements in nuclear emulsions exposed on low altitude polar orbiting satellites from 1961 to 1968. Except for the increases caused by "Starfish" is 1962, no large, short-time scale fluctuations were observed prior to 1966. The decay following "Starfish" was initially consistent with ionization loss, but 1964 and 1965 data indicate consistency with a decrease in atmospheric density, as expected at the minimum phase of the solar cycle. The 1966 flux levels tend to be lower than the 1964-1965 flux levels, as expected as atmospheric densities increase again. The 1968 flux levels are even lower, and the data are consistent with pre-Starfish values.

Page 1433-DG2

Pulsars and Cosmic Radiation. M. V. K. Apparas.

The recently discovered pulsating radio sources give out radio energy at a rate of 10^{28} to 10^{29} ergs/sec. It is possible that they give out particles with a total energy content several orders of magnitude higher. Taking into account their number density, it is suggested that pulsars could significantly contribute to the cosmic-ray intensity of the Galaxy.