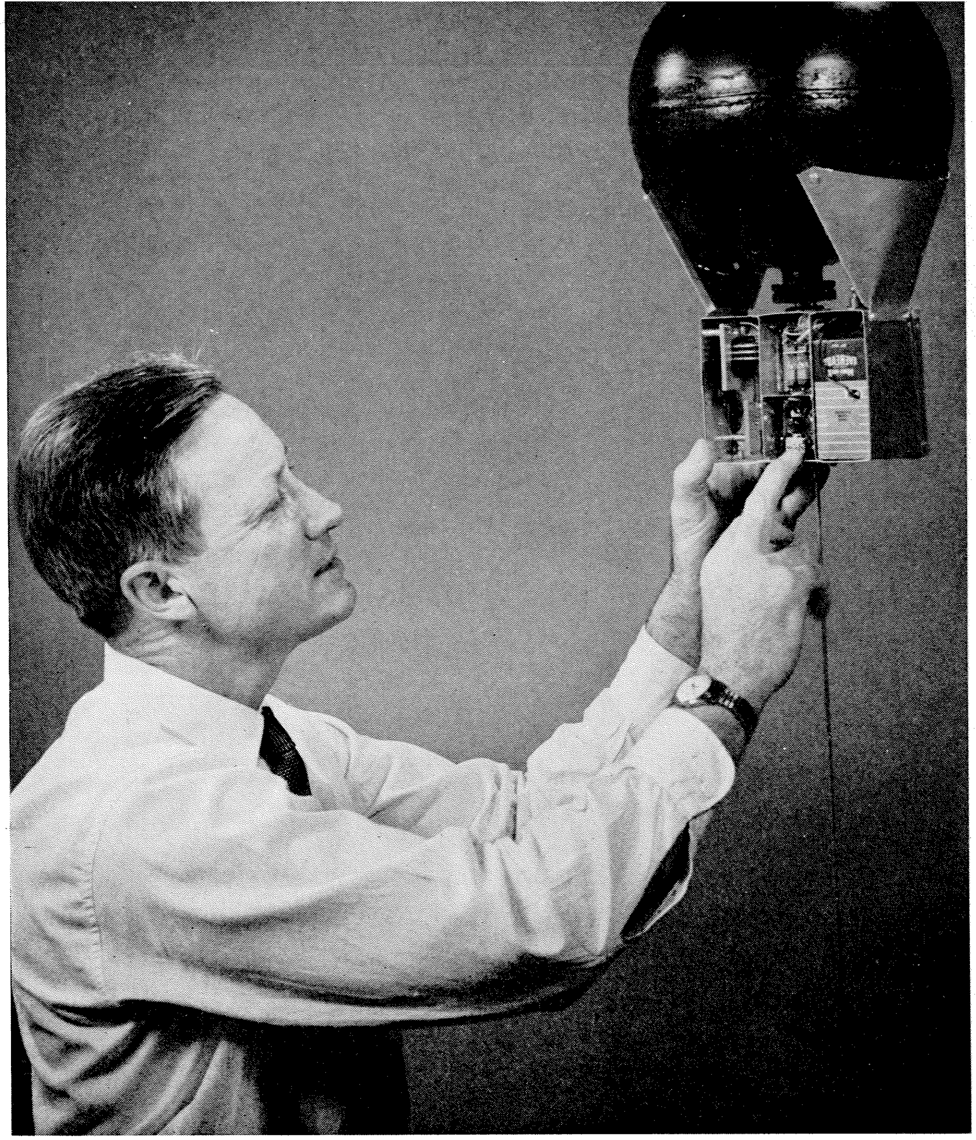


Victor Neher, professor of physics, with the ionization chamber for measuring cosmic rays which is carried up to high altitudes by balloons. The chambers are used mainly in Polar regions, where cosmic rays are most intense.

Cosmic Rays —Past, Present, and Future

by H. V. Neher

I am sure that few of those individuals, in the years before the first World War, who concerned themselves with that mysterious phenomenon later to be called cosmic rays, ever thought that their infant would develop into the adolescent that we know today. I say adolescent because there is every indication that our knowledge of this aspect of nature still has decided growing pains and one may reliably predict that a fully matured understanding will not come for a good many years. After all, our present knowledge has developed only very slowly and it has taken 50 years to arrive where we are today.

Let us first get our thinking straight as to what cosmic rays are. To do this, let us tell you what goes on right here on the Caltech campus, in a small building called the cosmic ray shack, just south of the Guggenheim Aeronautical Laboratory. Set up in there is a so-called cloud chamber big enough to walk into. It measures five feet tall, five feet wide, and two feet deep. Inside this space are a number of iron plates to absorb the particles, and a gas which can be expanded to make visible the tracks left behind by cosmic ray particles. Eugene Cowan, associate professor of physics, whose child this is, has taken some most extraordinary photographs of what goes on in this chamber. Sometimes simple events take place. At other times some very complicated situations develop.

None of us is aware, from any tingling or feelings, that cosmic rays are constantly passing through our

"Cosmic Rays" is a transcript of a talk given to high school students and teachers visiting the Caltech campus on Students' Day, December 3, 1960.

bodies. Perhaps this is best, for, if we could see the showers of particles that continually bombard us from above, we might not always be in such a tranquil state of mind. It would not be comforting to look overhead and see a skyrocket type of burst over our heads and then see these particles come out the other side of our bodies. It may console us a bit to realize that all during our lives and our ancestors' lives, from time immemorial, this bombardment has gone on.

The inability of our senses to detect directly the incidence of different kinds of radiation is one aspect of modern science to which students must become accustomed. When the dentist takes an X-ray photograph of your teeth, you feel nothing. Yet each set of X-rays so taken constitutes an appreciable fraction of the maximum total dosage during your lifetime.

Several days ago one of my graduate students and I were calibrating one of the instruments we hope to send into space, using a strong cobalt-60 source of gamma rays. You could carry this piece of cobalt around in your pocket and hardly be aware of its weight, but were you to do this for any length of time you would most surely suffer ill effects. Naturally, no sane person would carry such a source of radiation around with him, but it behooves all of us to be aware of these dangers and to believe the instruments that tell us that which our five senses do not reveal.

Going up

To continue our story about cosmic rays, we might imagine that this room and the people in it are earthbound no longer but are free to move wherever we wish, at will. Starting, then, here in Pasadena, let us head straight upward. Before leaving we note the rate at which a cosmic ray detector, known as an ionization chamber, goes off, indicating the intensity of cosmic rays in our room. At 10,000-ft. elevation we pause to observe the conditions within and without our room. We note first that cosmic rays have increased in intensity about four times. An observer on the roof tells us that we are on about the same level as the distant mountains and that he can discern the City Hall of Pasadena through the thick pall of smog directly below.

Next we pause at the 25,000-ft. level. Here we find that cosmic rays have increased 30-fold over what they were at sea level. Imagining that our room is a huge cloud chamber, we look up and see almost a continuous rain of particles coming down upon us. Not all of them come through the ceiling above, but as we go up, more and more of them come in through the side walls. Reinforced concrete is an excellent generator of new particles and reveals that few of these came here from outer space, but that more than 95 percent of them have been generated in the atmosphere above us, or in the walls or ceiling of our room. They are therefore called secondary particles and they consist chiefly of so-called mesons (mu-mesons to be exact) that are created by the primary particles. They live a short time (a few microseconds on the average). But in that time they go sufficiently far for some to penetrate to sea level and even many feet into the earth.

At this 25,000-ft. altitude each of us is being hit by some 2,000 particles per second, most of which go right on through and down into the atmosphere below. Our observer outside, in looking through the pressure window, informs us that the only signs of life here are a few military aircraft, although some civilian craft may be seen far below as they are letting down to land at, or are gaining altitude after taking off from, the Los Angeles International Airport.

Cosmic ray intensity at 60,000 feet

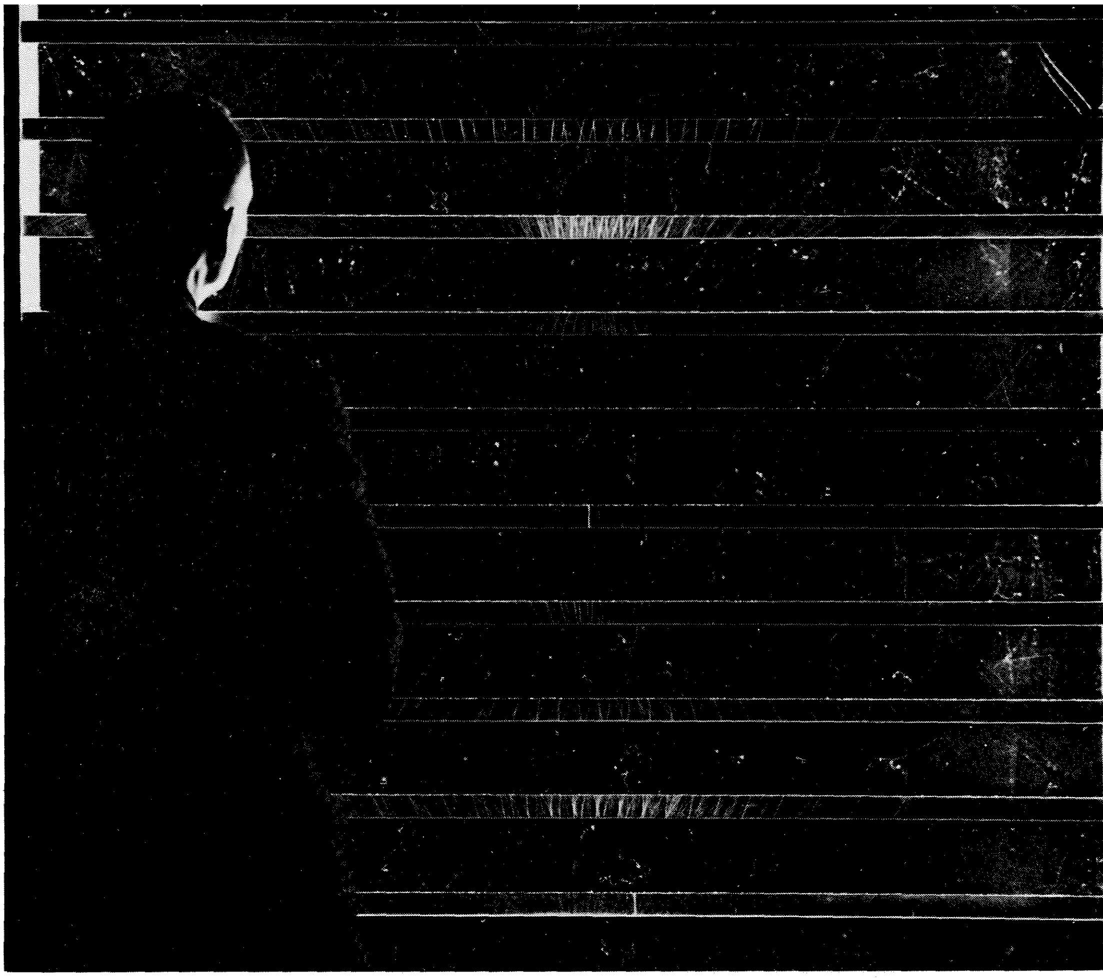
Continuing our journey upward we next pause at 60,000 ft. Here we note that cosmic ray intensity has climbed to 100 times that at sea level. Our ionization chamber is now discharging very rapidly and our room is pretty well filled with charged particles coming from almost every direction, except from below. With some study we learn that something like two-thirds of the particles passing through our room are still secondary particles that have been formed by the primaries colliding with the nuclei of the atoms composing the atmosphere above us. Some – in fact, an appreciable number – of these events occur as the primaries strike the nuclei of atoms composing the concrete and iron in the walls of our room.

Our observer outside informs me that at this altitude the sky is getting dark and there is no sign of life. "Wait a minute," he says. "There goes something in the distance. It's headed straight up. Ah yes, it must be that X-15 from Edwards Air Force Base."

We pause next at 100,000 feet. The air pressure here is only 1 percent of that at sea level. Surprisingly, the cosmic ray intensity is less here than it was at 60,000 feet. We also find, with some experimentation, that most of the particles here are primaries. We conclude, then, that the reason the number of particles is greater at 60,000 feet than it is here is because each primary particle, in striking the nuclei of the air atoms, forms several charged particles. Thus there is a buildup of numbers, or intensity, as the radiation passes downward through the atmosphere, reaching a maximum at about 60,000 feet. Then absorption begins to play a dominant role and there is a rapid decrease from there on down.

While we are at this altitude, let us find out what we can about the primaries. We use photographic emulsions, cloud chambers, and various kinds of counters in our experiments. Also we use the knowledge we have about mathematics and physics.

We find that many of these particles go through a foot of lead or more and that they leave tracks in our photographic emulsions and cloud chambers. After considerable analysis we learn the following facts:



Eugene Cowan, associate professor of physics, watches events taking place in his 5'x5'x2' cloud chamber.

1. Most of the particles are high-speed protons. We note with considerable interest that protons are the nuclei of hydrogen atoms, which make up 90 percent of the matter in the universe. And, in fact, we find that 84 percent of cosmic ray particles are protons.
2. We also find alpha-particles or the nuclei of helium atoms. In fact, some 15 percent of the primaries are identified as helium nuclei and we remember that astronomers tell us that helium makes up some 10 percent of the mass of the universe.
3. We find heavier nuclei in much the same proportion as they exist in the sun and in meteorites, up to and including iron nuclei.
4. These nuclei of the common atoms are the things we see shooting through our cloud chamber in all directions, and the things which are passing through us, here at 100,000 feet above Pasadena. It takes a little experimentation and knowledge of physics to learn that they are really going at great speeds. In fact, they might be called celestial bullets traveling at speeds very close to the velocity of light – i.e. nearly 186,000 miles a second.

   It is better to talk about the energy of these particles rather than their speed. We soon become accustomed to talking about their energy in terms of electron volts, or the energy these electrically charged particles would gain in being accelerated by an electric field where the change in potential was so many volts. Thus we may speak of a particle with 1000 electron volts (ev) of energy – meaning that, if it has a single electric charge (i.e., a charge corresponding to a single electron), its energy is definite and equal to what it would have by going between two metal plates with a difference of potential of 1000 volts.

   When we try to express the energy of our cosmic ray particles in terms of electron volts we must go higher than our national debt. In fact, we find them having energies all the way from a hundred million electron volts to a billion billion electron volts.
5. The numbers of these particles at the 100,000-ft. level is such that through each cubic centimeter of volume there will pass something like five particles per second. This would give you about a maximum recommended dose of radiation if you were to stay at this altitude for years.

As we continue our journey upward the sky becomes completely dark except for the stars and the nearest star, our sun. Below, the earth is bright in the sunlight, and the distant horizon is beginning to take on a noticeable curvature. The intensity of cosmic rays has dropped a bit from what it was at 100,000 feet, but beyond the 100,000-ft. mark – and on out to a million feet from the surface of the earth – there is not much change.

As our distance from the earth becomes 400 to 500 miles, we find that our cosmic ray detector indicates an increase of radiation and we realize we are entering the inner Van Allen radiation belt. We realize also that we are fortunate in having chosen to go up at the latitude of Pasadena, because we will pass through only the northern fringes of this belt and hence will not receive a lethal exposure to charged particles. Had we gone up from the equator, we would have passed directly through this band, and might not have survived – depending, of course, on how long we took to go through. This band is several thousand miles thick and consists of high energy protons and electrons. The walls of our room will stop most of them, but their numbers are such that if only a small fraction got through the walls, the effects would be disastrous. Furthermore, the high energy electrons striking the walls on the outside would give rise to X-rays and these *would* penetrate the walls and give us all a heavy exposure.

The protons in this inner Van Allen belt, we are told, come from the bombardment of the atmosphere of the earth by cosmic ray particles, which eject upward high speed neutrons resulting from nuclear collisions in the atmosphere. These neutrons do not live very long but change into high speed protons and electrons. These charged particles then become trapped in the earth's magnetic field and remain for long periods of time.

Continuing our journey, we note that at about 2000 miles out the radiation drops slightly; then, when we are out 4000 to 5000 miles, the radiation begins to increase again. We realize we are passing into the outer radiation belt. Inside our room with its heavy concrete walls, few of the electrons that exist in this band will penetrate. We will again find X-rays in our room, however, generated by the impact of these electrons on the outside of the walls. We should not linger long here, but continue outward.

At about 10 earth radii, or at about 40,000 miles out, we come to the outer boundary of the outer radiation zone. The reading of our cosmic ray detector drops down to a low value and we interpret this as meaning that we are now detecting cosmic rays only. The intensity is about what we measured over Pasadena when we were at an altitude of 30,000 to 40,000 feet.

As we continue outward no changes in the cosmic ray detector occur and we are getting bored by the monotony of the situation.

But what is this? What has gone wrong with our ionization chamber? It is counting a hundred, a thousand times more than normal. We had better get back to earth fast, where we have the protection of the earth's magnetic field, which turns away low energy particles; and the protection of the earth's blanket of air, which absorbs the effects of most of the particles that get through the earth's magnetic field.

Back here on earth we learn that, while we were out there, a very intense bright spot occurred on the sun which not only gave out a burst of ultraviolet light, but also generated a burst of high energy protons which reached the earth in a matter of minutes after leaving the sun. We also learn that this was one of the smaller solar flares, which caused only slight disruptions of radio communications on the earth. Even so, the intensity of protons was such that, had we stayed out there for a few days, we would have had a lethal dose of radiation. Had this been a really big solar flare, a few hours exposure would have been sufficient.

The walls of our room would have stopped many of these solar protons, but many of them would have been energetic enough to go through, and in fact to go through any reasonable thickness of shielding material which a rocket ship might have for lining the walls of its living quarters.

Solar bursts and astronauts

Will these solar bursts be damaging to the astronauts of the future? The answer is yes – unless by chance no solar outbursts occur while the space ship is out in space. So far this year 11 such bursts have occurred. The sun is now becoming more quiescent and will continue to do so for the next 3 or 4 years. There will be these sporadic bursts, however, that will, on the average, become less frequent. If I were to be the man in space I would certainly prefer to go in 1964 rather than in 1961. 1965 might still be a good year, but by 1966 the sun will start to become active again and the chances of a safe journey to the moon and back will be very much decreased. By 1975 the sun will again be quiet.

Because of the dangers of these radiations in space, which are unpredictable as of now, experimentation in space can best be done by automatic apparatus – leaving the astronaut home. There is much to be learned about the conditions in space, including what causes cosmic rays to change by at least a factor of five during a solar cycle. I am sure that, in the years to come, many new things will be discovered about the environment in interplanetary space so that we may become more aware of the nature of the universe in which we live.

I see that we have all gotten back from our journey safely. I hope none of you is any the worse for having taken this imaginative trip out into our solar system.