for the program in any way, the range and reliability of the equipment having been proved on rainstorms. It must be acknowledged that the hurricane which struck New Orleans on September 3, 1948, passed within 300 miles of the radar. No indication of a hurricane or even of rain was obtained during its course. However, this particular disturbance barely qualified as a hurricane, the highest wind velocity being 70 mph. Undoubtedly it did not reach the altitude required for radar observation at this extreme range.

Cosmic Ray Instrumentation

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Cosmic ray work is a subject rich in examples of advances in instrumentation leading to great discoveries in pure science. Cosmic ray research started, in fact, as instrument research, as the investigation of the leakage of electricity through the air in electrometers. Coulomb (1785) can be considered its founder. His career exemplifies the mutually beneficial interaction between basic research and instrument development. He first determined the law of torsional elasticity, the way in which the elastic constant depends on the radius and length of the cylinder. He then used this knowledge in the construction of a torsion balance of unheard of sensitivity. With this instrument, which could measure forces down to 0.005 dynes, he discovered the inverse-square law of force between electric charges. He then made a more sensitive torsion balance, readable to 0.001 dyne, with which he was able to prove, long before Faraday's ice pail, that there is no electricity on the inner surface of a conductor in equilibrium. Like everyone who has experimented with static electricity, Coulomb observed the apparently inexorable leakage of charge. He, however, studied it quantitatively, and resolved it into leakage along the supports and a leakage through the air. He planned a careful study of the dependence of the rate of leakage on the nature of the gas, its density, and its humidity, but had to postpone the project for lack of "instruments to measure exactly the purity of each gas and its humidity." Had Coulomb carried out this program, he would have been well into the physics of ionization chambers.

More than a hundred years later, in 1900, it was found that the conductivity of the air is due to continual ionization, and C. T. R. Wilson, in 1901, published the bold speculation that this ionization is due at least partly to an extremely penetrating radiation from outside the earth. In 1912-13, Hess and Kolhoerster obtained convincing evidence that there is an ionizing radiation coming down from on high, and by 1926 the scientific world was on the whole convinced of the existence of cosmic rays.

An outstanding example of an ionization chamber now in use for the continuous recording of cosmic ray intensity is the so-called Carnegie Model C, designed by Compton, Wollan, and Bennett in 1934. In this instrument the cosmic ray ionization in a 19.3-l sphere of purified argon compressed to 50 atmospheres is balanced against the ionization in a small chamber due to the beta rays from a uranium source of adjustable position. The collecting electrode, common to the large chamber, whose wall is at +250 v, and to the balancing chamber, whose other electrode is at −250 v, is connected to a Lindemann electrometer, the position of whose needle is recorded photographically through a microscope. The use of balancing makes the readings largely independent of voltage and temperature variations. With its 10.7-cm lead shield around it, this instrument has an average cosmic ray current at sea level of about 2×10^{-13} amperes, corresponding to about 15 fast particles per sec. About once a day there is a "burst," corresponding to the simultaneous passage of more than 500 fast particles.

An extremely useful wartime development in ionization chamber technique is the use of electron collection coupled with fast amplifiers. The leaders in the application of this technique to cosmic ray problems have been Rossi, Bridge, and Williams, who have thereby made important advances in our knowledge of high energy nuclear interactions. It is possible to rid argon of electronegative impurities, so that the electrons formed in the ionization process are collected free rather than attached. Their drift velocity in the direction of the applied field is on the order of 1000 times greater than those of the massive ions. Under appropriate conditions of field geometry and gas filling, a fraction of the total pulse height exceeding 90% is attained in a few microseconds. This makes possible the use of ion chambers in relatively fast coincidence with other chambers and counter tubes. Furthermore, the same workers, together with Hazen, have shown how the shape of the ionization pulse, as photographed on a fast cathode ray oscillograph sweep, gives information on the initial spatial distribution of ions, so making it possible to distinguish between bursts due to many fast particles spread through the chamber and bursts due to "stars" of a few heavily ionizing particles.

The ionization chamber is merely the most venerable of the many instruments now used in cosmic ray research, each of which has been responsible for tremendous advances. The instruments of cosmic ray research are the instruments of nuclear physics, just as, for example, the instruments of conventional astronomy are those of optics.

The most striking feature of cosmic ray nuclear physics is the low intensities with which one has to deal. In the Carnegie Model C ionization chamber that I mentioned the flux of penetrating particles through a sphere 33.2 cm in diam is only about 15 per sec at sea level in high latitudes. The increases in intensity at very high altitude do not exceed several hundred times; it is sometimes necessary, on the other hand, to go below ground or water, where the intensities are decreased by similar factors. A second feature of cosmic rays is their heterogeneity in composition, energy, and direction. This means that as a rule the more clean-cut in design an experiment is, the longer will it take to obtain statistically significant data. A third peculiarity of cosmic rays is their relative constancy, a feature which atones to some extent for the first two by making it possible to extend the experiments in time. Thus, in cosmic ray work one needs detectors of large size that function reliably over long periods of time. It is desirable, therefore, in a counter experiment to measure concurrently all the rates that one needs to know in order to decide whether the data are reliable. Thus the amount of apparatus devoted to monitoring often exceeds in bulk the apparatus needed for measuring the counting rate with which the experiment is concerned. In this pioneering branch of nuclear physics, one is out alone on the frontier; there is little established knowledge to go by, and one must take infinite pains to be sure that an effect one finds is not due to some equipment failure in the middle of the night or to an erratic behavior which might fail to show itself during an occasional test. It is particularly useful in this regard to record all counts on the moving strip of an operation recorder.

Certainly one of the most fruitful recent developments in cosmic ray instrumentation has been the application of electronic techniques to the sorting out of pulses, as regards time of occurrence and amplitude. The physicist now has at his disposal a potent arsenal of basic circuits for this purpose. Many of these circuits were developed before the war, but it took contact with the radar and atomic bomb projects to bring home to American physicists the possibilities of large scale application of electronic circuitry.

Dynamic Accuracy in Temperature Measurement

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The dynamic accuracy of a measuring instrument is concerned with its behavior under changing or dynamic conditions; likewise, its static accuracy is concerned with its performance under static conditions. Since it is relatively easy to define the static test conditions and to reproduce them whenever necessary, the usual accuracy specifications are limited to the static accuracy.

All practical temperature-measuring elements are imperfect dynamically simply because some heat is required to change their temperature and there is only a finite surface area through which the heat can flow. Consider a temperature-measuring element or bulb having a heat capacity of 0.004 Btu per °F and a surface area of 0.024 sq ft. If this element be immersed in a fluid flowing at such a velocity past the surface that the coefficient of heat transfer is 50 Btu/hr/°F/ft^2, the dynamic characteristics may be established. If the temperature is increasing at a rate of 20° F per min, the amount of heat flowing into the element is:

$$q = (20)(60)(0.004) = 4.8 \text{ Btu/hr.}$$

All of this heat must flow through the fluid film surrounding the bulb and, since the rate of heat flow is constant for a given rate of temperature change, the temperature drop over the film may be calculated from the steady state heat transfer equation

$$q = h\,A\,\Delta T$$

$$\Delta T = \frac{q}{hA} = \frac{4.8}{(50)(0.024)} = 4^\circ \text{ F}.$$

Thus, in order to keep the element temperature rising at a rate of 20° F per min, the fluid temperature must remain 4° F higher. In this example, the dynamic error of measurement is 4° F. Similarly, an 8° F drop would be required to cause the element to change twice as fast, or 40° F per min. The dynamic error then varies with the rate of temperature change of the thermal element, so it is generally more convenient to express the dynamic characteristics of a given element in a given medium as the ratio of the dynamic error to the rate of temperature change. This ratio Z has the dimensions of time and is called the "dynamic lag."

$$Z = \frac{(\text{dynamic error})}{(\text{rate of change})} = \frac{4}{20} = \frac{8}{40} = 0.2 \text{ min.}$$

When defined in this way the dynamic lag is in fact the time by which the thermometer reading lags the true temperature when both are changing at a constant rate.

Reduction of dynamic error. In terms of the bulb heat capacity, C, its area A, and the heat transfer coefficient h, the dynamic lag is

$$Z = \frac{C}{Ah}.$$

This equation indicates some of the possibilities for reducing the dynamic lag and thus improving the dynamic accuracy. Any increase in the coefficient of heat transfer produces a corresponding decrease in Z. This means that the bulb should be located at a point where the fluid velocity is high, since h increases approximately as the square root of the velocity. By the same token, the coefficient of heat transfer is much greater in agitated liquids than in gases or even vapors at low velocity, so if a choice exists the better medium should surround the bulb.

Another possibility of reducing the lag is to change the thermal element to reduce its heat capacity or increase its area, that is, reduce the value of C/A. The most common method is to reduce the diameter of the element. Occasionally, finned bulbs are used, although the improvement that can be obtained is limited. In general, for bare bulbs or thermocouples, without a protecting well, the internal thermal resistances are negligible compared to the fluid film resistance and the element can be considered as homogeneous and characterized by a single heat capacity and a single thermal resistance as was done in the previous example. Actually, there are small thermal resistances throughout the element which add a fraction of a second to the lag caused by the fluid film, but the latter are much larger, varying from a second or two up to several minutes. This is not the case for thermal elements installed in protective wells, unless exceptionally good thermal contact exists between the sensitive element and the well, since an air space of a few ten-thousandths of an inch between the two can