IONOSPHERIC AND

SOME of the geophysical research being conducted by the Air Force Cambridge Research Center, Air Research and Development Command, was described in an earlier issue (*Physics Today*, p. 10, February 1953). It may be recalled that the Terrestrial Sciences Laboratory investigated the properties and interactive effects of the land, oceans, and atmosphere using techniques and instrumentation of seismology and acoustics. The occupation of Ice Island T-3 in the Arctic research program was given as an example of the interrelationship of terrestrial and atmospheric studies. Microseismic activity was correlated with meteorological conditions and the anomalous propagation of sound was described as a tool in the determination of temperatures and winds at high altitudes.

In the Atmospheric Analysis Laboratory research in weather prediction on a mathematical and objective basis is emphasized and numerical forecasting techniques have been developed. Atmospheric motions are studied both from laboratory models of circulations similar to those in the atmosphere and through the use of controlled altitude balloons. To improve safety in flight, the nature of disturbances set up by mountain barriers constitutes a major study in this laboratory.

In the Atmospheric Physics Laboratory the phenomena of atmospheric electricity, optics, thermodynamics, nucleonics, and chemistry are investigated both in the field, by means of aircraft, balloons, and rockets, and in the laboratory. Formation and dissipation of cloud droplets, raindrops, and ice crystals and the physics involved in artificial seeding of clouds are studied. In connection with the study of visibility at high altitudes, the scattering of light by air molecules is measured. In the field of atmospheric electricity, aircraft equipped as flying laboratories measure the distribution and mobility of ions generated by cosmic rays, radioactive elements of the earth, and natural phenomena such as thunderstorms. An artificial sun has been constructed in the laboratory in the form of an ultraviolet vacuum monochromator with which samples of atmospheric gases are irradiated and analyzed.

Thus far, only the research in those laboratories concerned with the earth proper and the atmosphere up to about 100,000 feet has been described. The work being accomplished in the upper reaches of the atmosphere by the Ionospheric Laboratory, the Upper Air Laboratory, and the Upper Air Research Observatory will be discussed in the present report.

Ionospheric Laboratory

The Ionospheric Laboratory is concerned principally with a study of the higher, ionized regions of the terrestrial atmosphere. Application of a wide variety of theoretical and experimental techniques in the radio and optical regions of the electromagnetic spectrum provides much important information on the constituents and their physical state in the higher atmosphere.

Experimental ionospheric investigations employ principally low radio frequency measurements of virtual height, absorption, and polarization. Analyses of these data provide a determination of electron and ion densities, collisional frequencies, heights of maximum ionization, and similar parameters in the atmosphere. A major portion of the theoretical ionospheric work is concerned with the construction of a dynamic model of the ionosphere consistent with the observed data. This study requires a consideration of such formative mechanisms as selective absorption of solar radiation by the atmospheric particles; changes in atmospheric composition, temperature, and density with height; the influence of the earth's magnetic field; physical and chemical reactions among the atmospheric particles; and high atmospheric wind systems.

Regions of abnormally intense ionization (sporadic E) are occasionally found imbedded in the E ionospheric layer at altitudes of 100–120 km. The large scale characteristics of sporadic E may be investigated by means of an analysis of abnormally distant radio contacts. Over four hundred radio amateurs operating in the frequency range 50–54 Mc/s furnished data on radio contacts made with other amateurs at distances where such contacts would normally not be expected. This information is screened to remove from consideration propagation paths involving tropospheric superfraction, auroral interaction, and reflection from the F2 ionospheric layer.

The simplest mechanism for scattering of radio waves by sporadic E "clouds", involving one ionospheric reflection point located at approximately the center of the great circle path between the transmitting and receiving stations, is also by far the most effective path, since it involves the minimum absorption of energy. The analysis of the screened data is based primarily on this simple one-hop model.

A plot of the mid-points of all sporadic E contacts observed in a given time period indicates the location and extent of sporadic E.

The presentation of sporadic E movements is facilitated by plotting a time sequence of "centers of mass" of agglomerations of sporadic E reflection points. Average speeds range from 125 to 210 km/hr. Individual sporadic E "clouds" may be followed for thousands of kilometers.

Spectrographic observations of the aurora and the very faint airglow furnish a wealth of information on the nature of the constituents in the ionosphere. Time-intensity variations of the aurora are being measured

This article was prepared by members of the staffs of the Ionospheric and Upper Air Laboratories and the Upper Air Research Observatory of the Geophysics Research Directorate, Air Force Cambridge Research Center, Air Research and Development Command.

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systematically at selected wavelengths, for correlation with the time variations of other geophysical phenomena such as ionospheric disturbances, magnetic anomalies, and earth currents. Supplementary to the more classical spectrographic techniques, auroral scientists are now employing radio wave scattering by the atmospheric regions associated with auroral emissions.

A theoretical study is now in progress on the formation of the polar aurora through the action of a stream of charged particles which emanates from the sun and interacts with the ionospheric and mesospheric particles after modification by the geomagnetic field. Other theoretical projects include the determination, by the methods of quantum mechanics, of the processses by which the bombarding particles excite and ionize the atmospheric constituents and thereby cause the aurora.

The atmosphere affords significant clues regarding its properties not only by emitting radiation, as in the aurora, but also by selectively absorbing solar radiation. The infrared region is particularly rich in atmospheric absorption. The investigations thus far have yielded valuable information on the concentration and vertical distribution of a number of minor permanent constituents of the earth's atmosphere including ozone, carbon dioxide, carbon monoxide, methane, nitrous oxide, ordinary water vapor, and deuterium hydroxide.

Upper Air Laboratory

The physics of the upper air is no longer merely a matter of scientific curiosity to a relatively small number of theorists working, for the most part, alone in universities scattered throughout the world. Recognition of an immediate military need for upper air data, coupled with the availability of rockets to carry instruments directly into this heretofore inaccessible region, has resulted in organization of groups such as the Upper Air Laboratory and the fifteen-odd university contractors under its sponsorship, all working within a carefully coordinated program.

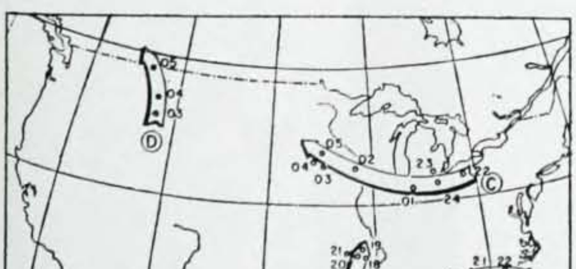

Fig. 1. Summary plot indicating movement of four sporadic E-region reflection areas during May 15–16, 1949. Numbers represent hours G.M.T.

Last month's issue of Physics Today contained an account of three of the six laboratories of the Geophysics Research Directorate of the Air Force Cambridge Research Center. The present article describes the other three laboratories.

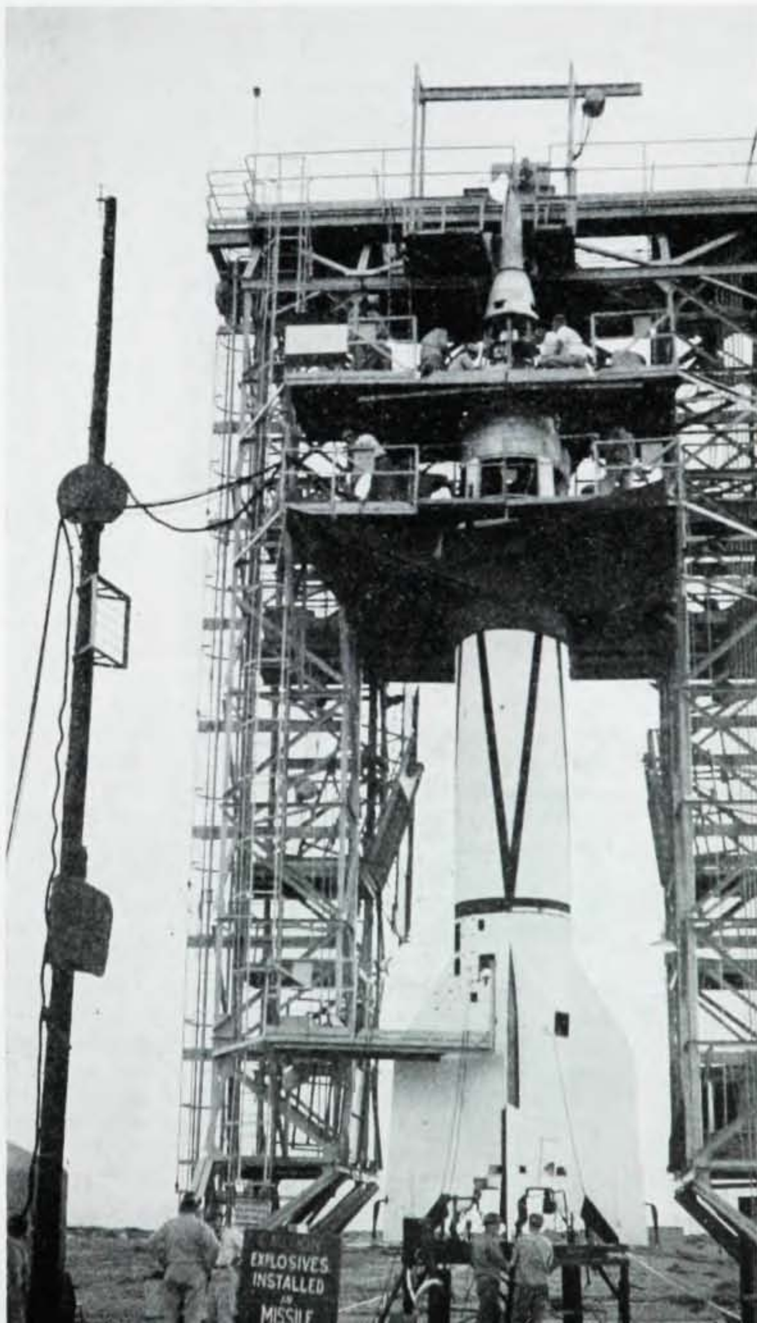

Fig. 2. Readying a modified V-2 rocket for flight.

The Upper Air Laboratory is staffed by specialists whose fields run the gamut from electronics through the conventional divisions of heat, light, sound, etc., to advanced mathematical theory. The business of instrumenting a laboratory that moves a mile per second and tends to disturb the very conditions one is attempting to measure requires close teamwork within such a group.

Obviously, if rockets are to be used efficiently, prior to devising suitable instrumentation, it is necessary to decide which parameters should best be measured during a rocket flight. Detailed theoretical study and related laboratory experiments determine which directly-measured data will provide the most reliable check upon existing theories, how much additional information can be computed or deduced from those data, and how accurately one can hope to measure them under the peculiar conditions of rocket flight. An increasingly important phase of this laboratory's activity is the application of modern methods for automatic recording and reduction of the large quantities of data accumulated during rocket and high-altitude balloon flights, and from various other patrol-type experiments.

Several types of pressure gauges are mounted at strategic positions on the rocket skin, and the telemetered data is used to calculate the variation of ambient pressure with altitude. Temperature values come indirectly from other parameters that are more readily measurable at very high altitudes; for example, actual determinations of aerodynamic characteristics of the rocket itself yield Mach numbers, which, together with known rocket-velocity data, give the speed of sound, hence temperature. Preparations are in progress to measure upper atmospheric wind velocities using data from a rocket-borne air-speed indicator system combined with known missile-aspect information. The latter results will contribute greatly to the physicist's understanding of the "mixing" of upper atmospheric constituent gases.

The advantages of obtaining radiation data free from the integrated absorption effects of the entire atmosphere are very great indeed. A series of rocket-borne, photometric experiments have been measuring day airglow, and, as the earlier results indicate the proper measuring ranges to be used in subsequent experiments, increasingly narrow-band filters and more sensitive photocells are incorporated into the apparatus. Such experiments have brought about a careful re-evaluation of the existing theories of light scattering, and provide unprecedented opportunities for checking them. A sun-seeker is used to keep the determinations of the solar constant, and, in an even more ambitious project, a small, rocket-borne coronagraph will photograph the spectrum of the solar corona far above the dust of the earth's atmosphere. A search is being made for infrared emission from the predicted (OH) layer at about fifty miles. A light-weight spectrograph will soon be flown to record the emission spectra from atmospheric gases. In this experiment, the air is scooped into a long glass tube inside the rocket skin, and excited by an rf voltage applied to a ring around the gas tube. Analysis of the recovered films should yield not only detailed air-composition data, but also clues concerning basic physical processes in the excited region.

Radio spectroscopy promises to be an especially powerful tool to the scientist studying the composition and state of the upper atmosphere. The immediate task of this new field is to compile the spectral tables needed for comparison standards. Very rapid progress is being made in this work.

Rocket-borne experiments are particularly useful in studying details of the actual structure of the ionosphere such as variation of ion density with height. Such data

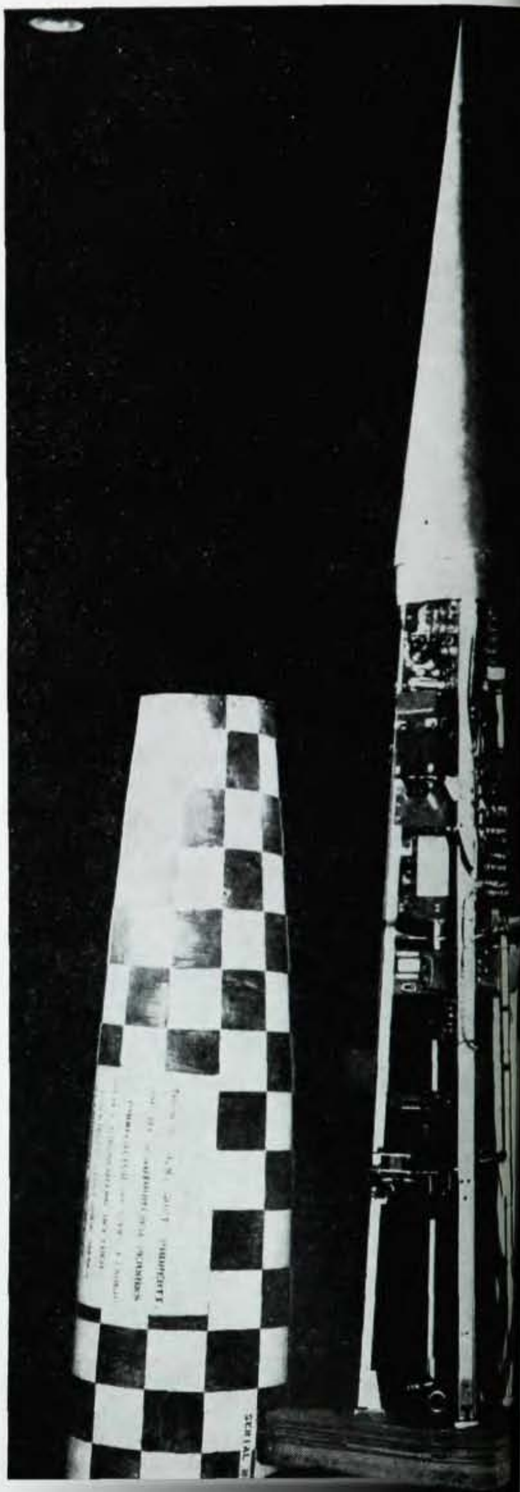

Fig. 3. Nose section of an AEROBEE rocket showing instrument installation.

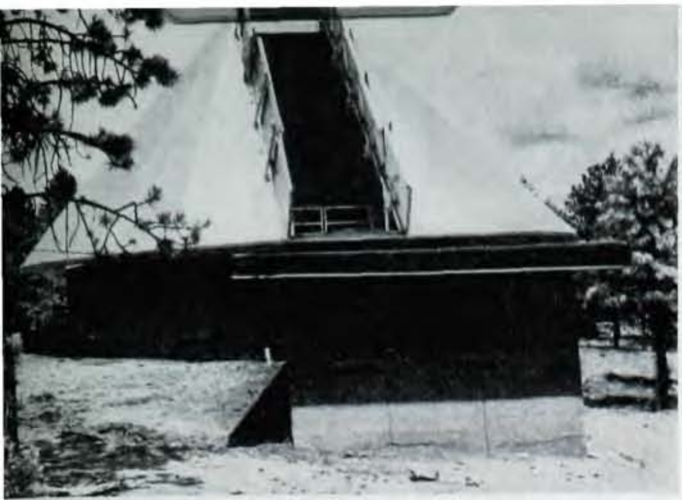

Fig. 4. Upper Air Research Observatory at Sacramento Peak, New Mexico.

are not forthcoming from ground-based probing experiments. Direct measurements also provide requisite information for setting up increasingly meaningful laboratory experiments in which it is possible to simulate certain aspects of the ionosphere while extraneous effects are eliminated. The resulting simplification, together with the opportunity to apply the latest techniques of measurement and control, often permits the experimenter to isolate and identify basic physical processes that are normally masked by coexisting effects in the actual ionosphere.

In one such series of experiments, electrons and ions are produced in rarefied gases by pulsed, electrodeless discharges, and, between pulses, the ionization decays slowly in a manner analogous to the decay of ionospheric ionization after sunset. Wall effects are greatly reduced by the use of a toroidal-shaped discharge tube with a magnetic field everywhere parallel to the tube walls. In another, the laboratory analogue of multiple ionospheric refraction is produced in a sample of ionized gas contained within a microwave cavity. The application of a strong magnetic field splits the original single resonant frequency into two components corresponding to the ordinary and extraordinary modes of polarization in the ionosphere. Such experiments open up new mathematical problems that challenge the ingenuity of the theorists in the group.

Upper Air Research Observatory

One of the major research projects of the Geophysics Research Directorate is a fundamental study of the influence of the sun on the terrestrial atmosphere. Fluctuations in the density, height, and stratification of the ionosphere are apparently due to changes in the ultraviolet and corpuscular radiations from the sun. These fluctuations have a direct influence on long distance radio transmissions, and recent investigations indicate that ionospheric variations may also affect the weather appreciably. If we are to develop sound methods for predicting ionospheric conditions, a thorough understanding of the mechanisms of the solar-terrestrial relations will be necessary. This requires a much deeper insight into the phenomena of the upper atmosphere and of the sun itself than we have at present. As a step toward filling the need for solar information, the Geophysics Research Directorate has established the Upper Air Research Observatory at Sacramento Peak, near Alamogordo, New Mexico.

The observatory was planned to carry out researches on the optical and radio emission characteristics of the sun. The initial emphasis will be placed on variations of the solar constant, the corona, flares, prominences, sunspots, and granulation, all of which are known or suspected agents of ionospheric disturbances. The design and construction of the necessary optical instruments and the planning of the support facilities were ably carried out under contract with the Air Force by the Harvard College Observatory, and by the High Altitude Observatory of Harvard and the University of Colorado at Boulder, Colorado. The Electrical Engineering Department of Cornell University has similarly built equipment for observations of solar radio noise.

Daily measurements are made of coronal brightness, as are records of all flares occurring on the sun during the daylight hours. These observations are combined with coronal data from the High Altitude Observatory at Boulder, Colorado, for daily transmission to the Central Radio Propagation Laboratory of the National Bureau of Standards, where they are used in predictions of radio disturbances. The daily flare record has proved particularly valuable and is the only one available at present. In addition, a five-inch prominence telescope makes motion picture records of solar prominences whenever the sky is clear.

The principal optical instrument of the observatory is to be a 16-inch apochromatic coronagraph which feeds light into a constant temperature laboratory where it can be analyzed by any one of the large variety of instruments. These include spectrographs of high and medium resolution, a photo-electric coronal photometer, birefringent filters for monochromatic observations of the corona, prominences, and the numerous disk features, either by photography or with the photoelectric photometer, and provisions for polarization studies and direct photography. The optical parts of the coronagraph are approaching completion at the High Altitude Observatory. The mounting consists of a rectangular steel spar 26 feet long, mounted equatorially and guided on the sun by a servo system actuated by photoelectric cells. It will eventually hold several solar instruments in addition to the 16-inch coronagraph, all of which may be used simultaneously.

The solar radio noise equipment will consist of receivers for recording the flux of radiations at 55, 205, 1420, and 3200 mc, and the direction of circular polarization at 205 mc. The 55 and 205 mc receivers have begun regular operation and preliminary comparisons of their records with those from the flare recorder show marked correlations. The 1420 and 3200 mc equipment are still under construction.

To relate the data thus accumulated to the properties and processes of the terrestrial atmosphere is the mission of the scientific team at the Upper Air Research Observatory.