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Spectroscopy in the Vacuum Ultraviolet

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I. INTRODUCTION

THE spectroscopy of the vacuum ultraviolet, like that of the far infra-red, differs in its techniques from the spectroscopy of the more accessible wave-length regions. However, spectroscopic data obtained in the vacuum ultraviolet must be considered as an integral part of the data obtained over all regions of the spectrum and in many cases these are the essential data necessary to establish the connection between the normal state of the atom and its excited states. Some of the techniques used in the vacuum ultraviolet are of interest because of the physical principles which they involve and because of experiments which they make possible in the related fields of optics, photoelectricity and photochemistry. A survey of this field must discuss the physical principles involved in experimental observations, must evaluate the observations already made and should indicate promising topics for further investigations.

Investigations of line spectra have provided methods of identification of the chemical elements and information about the structure of the atom. For complete observation of the spectrum it is often necessary to include regions of wave-length shorter than λ1850.[1] Here, because of the opacity of oxygen, it is necessary to remove oxygen from the light path, which is usually done simply by removing the air from the optical system. This region will, therefore, be referred to as the "vacuum ultraviolet" instead of, less definitely, as the "extreme ultraviolet." As a background to a discussion of the spectroscopy of this region it is perhaps worth while to recall a few well-known facts about spectroscopy in general.

Empirical measurements have been made of the wave-lengths in the visible spectra of (very nearly) all of the elements. Such measurements provide, qualitatively, certain identification of the presence of each of these elements, whenever the particular group of lines belonging to that element is again observed. And whenever, as for example in certain astronomical observations or with a beam of high speed ions, there is a considerable relative velocity between the source of light and the observer, the Doppler shift of these wave-lengths permits the determination of that relative velocity. Further empirical investigations led to the discovery of the various types of regularities among spectral lines. Most significant of these was the Ritz combination principle, according to which the wave numbers (wave-lengths per centimeter) can be arranged as differences between spectroscopic terms. The Bohr-Sommerfeld theory and, subsequently, the wave-mechanical theories of the atom have identified these spectroscopic terms with energy states of the atom. These theories have proposed atomic models to account, qualitatively or quantitatively, for the number and arrangement of these energy states. Spectroscopy thus became a tool for the study of the energy states of the atom (and later the molecule) and of the binding energy of its extra-nuclear electrons. When the energy states are known in reasonable detail, the spectrum becomes an index of the excitation conditions in the light source, whether that source be the atmosphere of a star or a gas discharge tube in the laboratory. Quantitative spectrochemical analysis has a firmer theoretical basis whenever the detailed excitation energies of the spectrum can be known.

First spectra (denoted by the Roman numeral I following the atomic name or symbol) are those of neutral atoms, second spectra (II) those of singly ionized atoms, and so on. Whether or not a given spectrum can contain lines in the vacuum ultraviolet depends on the ionization potential of the atom (or ion). If the ionization potential of an atom or ion exceeds about 6.7 volts (12336/λ1850), at least the higher members of some of its spectral series will lie within the vacuum region. Whether or not important lines, that is lines giving information as to terms (energy states) not otherwise accessible, lie in the vacuum region depends on the arrangement of states in the atom (or ion). Generally speaking, investigations of the vacuum ultraviolet become important if the ionization potential exceeds 10 volts. There are cases where it is worth while with an ionization potential as low as 8 volts. A survey of available data, with reasonable estimates for the spectra not yet analyzed, indicates that important data lie in the vacuum ultraviolet region for the first spectra of about 50 percent of the elements, for the second spectra of about 85 percent of the elements, and for the higher spectra of all elements.

The region of the vacuum ultraviolet extends out into the region of soft x-rays and is indistinguishable from it. Air gradually again becomes transparent to x-rays of wave-length less than about λ2. It seems suitable to refer to the radiation as ultraviolet or "optical" if it arises from transitions of one or more electrons of the most loosely bound shell of electrons present in the radiating atom or ion. The radiation may be considered as x-ray if it arises from transitions following the removal of one or more electrons from one of the more tightly bound shells of electrons in the atom, without the removal of the more loosely bound electrons. Optical radiations, in this sense, have been investigated as far down as λ12.1, while soft x-rays have been measured up to wave-lengths of a few hundred angstrom units. Beutler has investigated the most interesting transition between these two, perhaps

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[1] Wave-lengths throughout this article will be expressed in angstrom units and will be denoted by the prefix λ. Nonspectroscopic readers are reminded that the angstrom unit is precisely defined by the statement that the red line of cadmium (under specified conditions of excitation) has a wave-length of λ6438.4696. For most practical purposes one angstrom unit may be taken as 10^{-8} cm. Readers are further reminded that the approximate limits of the visible spectrum are λ4000 (violet) and λ7000 (red).

arbitrary, classifications of excitation conditions. His work will be discussed in a later section.

In surveying our present knowledge of line spectra in the vacuum ultraviolet, it is obvious that much important observational work done more than about ten years ago must now be considered merely as a reconnaissance survey. The spectrographs now available give considerably greater dispersion and the wave-length standards have been greatly improved. Much of the earlier work must now be repeated. This is particularly so for those elements having complex spectra, where inaccurate data may make analysis of the spectrum impossible. It may further be noted that the spectral region first investigated by Schumann (and often described by his name), from λ1850 to λ1200, has not been as thoroughly explored by subsequent workers as the region of still shorter wave-length more recently discovered.

The historical development of the extension of spectroscopy from the visible to the regions of increasingly shorter wave-length will be treated most briefly since several excellent summaries have already been published.[2] Schumann (1893, 1901) made the first investigations of the vacuum ultraviolet. He used fluorite prism and lenses in a vacuum spectrograph and prepared the special photographic plates that now bear his name. Schumann reached wave-lengths now known to be in the vicinity of λ1200. He was unable to reach shorter wave-lengths because of the absorption in the prism and lenses. In the absence of exact knowledge of the dispersion of the fluorite, Schumann could not determine the wave-lengths of the lines he observed. Lyman (1906) substituted a concave grating for the fluorite prism and lenses. He was able to make wave-length measurements in the region pioneered by Schumann and to extend it further, down to about λ500. Millikan (1921) introduced a more powerful source of light, the hot spark, and extended observations to somewhat below λ200. Millikan and Bowen carried out extensive observations on the spectra of isoelectronic sequences at a time when these data were most opportune in the development of spectral theory. A. H. Compton and Doan (1925) used a grating at grazing incidence to measure x-ray wave-lengths. The method was extended by Thibaud (1927) (with a plane grating) and Osgood (1927) (with a concave grating) to the measurement of soft x-rays and by Hoag (1927) to the wave-lengths of the vacuum ultraviolet. This closed the gap then existing between the vacuum ultraviolet and the soft x-ray spectral regions. The grazing incidence vacuum spectrograph was developed most fully in Siegbahn's laboratory in Upsala, where during the last ten years Edlén has carried out very extensive investigations, especially on the spectra of many times ionized atoms. No summary, however brief, would be complete without mention of the important astrophysical applications, by Bowen, of vacuum ultraviolet data in the interpretation of the spectra of the gaseous nebulae.

II. TRANSMISSION OF GASES AND VACUUM REQUIREMENT

To appreciate the practical requirements for investigations in the vacuum ultraviolet, it is useful to summarize the pertinent data on the absorption spectra of the principal constituents of the atmosphere. It will be seen that oxygen is the chief offender. "Forbidden" absorption spectra (those from processes of extremely low transition probability) need not be considered for optical paths measured in meters. The absorption spectra of secondary photochemical products can also ordinarily be neglected in these considerations. Both of these neglected factors conspire in the earth's atmosphere to limit the observation of solar and stellar spectra to wave-lengths greater than about λ3000.

Oxygen

The Schumann-Runge system of bands of O_2 appears strongly in absorption and has been measured by Curry and Herzberg (1934) under high dispersion. It commences near λ1950 and converges to a limit at λ1759, beyond which lies a strong band of continuous absorption. This system of bands makes observation progressively difficult below λ1950. λ1850 is usually taken as the working limit for observations in air. Because of the discontinuous nature of the absorption in this wave-length range, observation of lines close to λ1850 is no guarantee that other lines, nearer λ1950, may not have been blotted out by one of the discrete bands in the Schumann-Runge system. For convenience the wave-lengths of the

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[2] See bibliography at end of text.

band heads in the Schumann-Runge system are listed in Appendix A.

Ladenburg, Van Voorhis and Boyce (1932) and Ladenburg and Van Voorhis (1933) have investigated the continuous absorption. The absorption coefficient has been determined quantitatively as a function of wave-length over the range from λ1670 to λ1330. The absorption is a maximum at about λ1450 and decreases rapidly below that wave-length. At the wave-length of maximum absorption, the intensity of radiation is reduced by half in a path length of only 0.0014 cm in oxygen at normal temperature and pressure. This is comparable with metallic absorption and is far greater than the absorption in the band lines. A second continuous absorption band due to O_2 commences at about λ1100 and extends at least to λ303 and probably to about λ160. Qualitative observations on this second continuous absorption band indicate that the absorption coefficient is of the same order of magnitude as in the continuous band between λ1750 and λ1300. Ladenburg and Van Voorhis have shown that these two absorption bands can together account for the form of the dispersion curve of oxygen as measured by Ladenburg and Wolfsohn (1932). The form of the band in the Schumann region is in good agreement with the theoretical calculations of Stueckelberg (1932, 1933).

Price and Collins (1935) have observed absorption bands in the region between the two absorption continua in oxygen. They were overlooked in earlier investigations where a line spectrum had been used as a background for the absorption measurements. The bands extend from about λ1250 to about λ650. The bands between λ1250 and λ1000 are relatively weak and appeared when the pressure in the spectrograph was of the order of 0.1 mm of mercury. The light path was 1.5 meters. The bands below λ1000 were much stronger and appeared with a partial pressure of 0.001 mm of mercury when the oxygen was introduced diluted in helium.

Nitrogen

Nitrogen appears to be transparent down to λ1450. A series of sharp narrow bands begins here and extends to λ990. The wave-lengths of these bands are given in Appendix A. Beyond λ990 continuous absorption sets in.

Carbon dioxide

Experiments by Leifson (1926) indicated band absorption commencing at λ1712 with very strong absorption commencing at λ1610. An investigation by Rathenau (1933) failed to confirm these results, but he found a set of absorption bands beginning at λ1174 and followed (near λ957) by a continuous absorption extending to at least λ270. Unless special precautions are taken one would expect considerable complication from absorption by traces of oxygen produced photochemically in the absorbing path. Groth (1939) has pointed out that the reaction $CO_2+h\nu\rightarrow CO+O$ is energetically possible in this whole wave-length range. Below λ1640 this reaction can give rise to atomic oxygen in the excited ^1D state. Since Groth (1937) has carried out the photochemical decomposition of carbon dioxide by the light of his xenon lamp (λ1470+λ1295), it is clear that there must be considerable absorption in at least part of this wave-length region. There is need for further investigation.

Water vapor

Rathenau (1933) found two absorption continua. The upper limit of one was at λ1780 and of the other at λ1340. Band series were superposed on each continuum. Hopfield (1938) reported diffuse bands extending from λ1400 to λ900, followed by a continuum extending toward shorter wave-lengths.

Rare gases

In argon, line absorption commences at λ1066 and the continuous absorption sets in at about λ800. In neon, the line absorption starts at λ743 and the continuum follows at about λ575. The amounts of helium, krypton, and xenon in the atmosphere are trivial, but they would make little difference even if more abundant. They are essentially transparent (except for a few sharp absorption lines in the two heavier gases) *at least* as far down as is nitrogen.

IT is generally easier to remove air than to rid it of troublesome constituents. Quantitative absorption data are available only for oxygen but there is no reason to believe that other gases give materially stronger absorption. That the absorption in oxygen over an optical path of 4 meters (in a typical vacuum spectrograph) shall not exceed $\frac{1}{2}$ at the wave-length of maximum absorption, it is necessary that the partial pressure of oxygen in the apparatus be reduced to the order of a thousandth of a millimeter of mercury. A convenient pressure range of residual gas is from a ten-thousandth to a hundred-thousandth of a millimeter of mercury. This is readily available with modern vacuum pumps and gives no noticeable absorption at any wave-length.

For limited spectral ranges it is sometimes convenient to replace air by pure nitrogen. This has been done in extending slightly the range of quartz prism instruments. The nitrogen is used at slightly above atmospheric pressure so that any leakage will occur outward and will not introduce contaminations. The method seems promising for small instruments, but the difficulties inherent in the method increase as some power of the dimensions of the apparatus, since more gas must be obtained at greater purity. To meet the previous criterion of a thousandth of a millimeter of mercury partial pressure of oxygen for a 4-meter optical path presents a considerable problem in gas purification. Helium and hydrogen offer other possibilities in this direction (hydrogen has absorption bands below λ1115 and a continuous absorption below λ850), but these have few advantages over nitrogen. Generally speaking, it would seem easier to evacuate the spectrograph than to fill it with a transparent gas.

Selwyn (1929) surrounded his light source (arc or spark) by an atmosphere of nitrogen and admitted the radiation into the vacuum spectrograph through a fluorite window. Shenstone (1938) replaced this window by a fluorite lens to form an image of the source upon the slit. He also improved the method for the introduction of nitrogen so that a steady stream of the gas, over the surface of the lens and toward the arc or spark, kept the lens clean. The light path in the nitrogen can be made quite short.[3]

If one wishes to go below λ1100 (the limit of transmission of lithium fluoride) some system of differential pumping is necessary. One such system was described by K. T. Compton and Boyce (1928). Modern pumping techniques should make it much more effective. An elaborate pumping system was once used by Cario and Lochte-Holtgreven (1927) to provide an argon "window" to prevent diffusion of metallic vapors from a light source to a quartz window. A similar device was used by Beutler (1933) to exclude them from the slit of a vacuum spectrograph.

From the data on nitrogen and oxygen given above, there appears to be a region of relative transparency in air between λ1300 and λ1100. This possibility was first pointed out by Hopfield (1922). The gap was confirmed by Ladenburg, Van Voorhis and Boyce (1932) and was later studied by Lyman (1935). Lyman found that radiations in the region between λ1100 and λ1250 could penetrate several centimeters at atmospheric pressure. But the transparency is merely relative. It is limited, in general by the tail of the absorption band with maximum at λ1450, and in particular regions is interrupted by the N_2 absorption band system, and by the O_2 bands discovered by Price and Collins.

Preston (1940) has measured the absorption coefficient of oxygen, nitrogen, dry air, carbon dioxide, and water vapor for one particular wave-length—the hydrogen line at λ1215. The value for nitrogen is very low and nitrogen may be considered as essentially transparent at this wave-length. The absorption coefficient in oxygen seems to be a function of pressure. This suggests that the absorption is due to pressure broadening of the neighboring O_2 band at λ1211 observed by Price and Collins. Preston finds that the intensity of the hydrogen line λ1215 is reduced to half in traveling 4.5 cm in dry, CO_2-free air at atmospheric pressure. The absorption coefficient of carbon dioxide is considerably larger, that of water vapor far greater. Schneider (1940) has measured the absorption coefficient of dry, CO_2-free air at 350 points between λ1596 and λ382. The light source used was a spark, with many lines, rather than a source of continuous

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[3] Professor Shenstone has informed the writer of the existence of fine absorption bands at wave-lengths *longer* than λ1450 in the spectra of metallic arcs operated in an atmosphere of nitrogen. The band structure is easily seen against those metallic emission lines which happen to be broadened by auto-ionization. The nitrogen molecule in its lowest vibrational state is unable to absorb in this particular wave-length range, but excitation in the arc may maintain a supply of nitrogen molecules in a suitable state to cause the observed absorption. It is not yet clear whether or not a similar phenomenon occurs in sparks in nitrogen. Comparative exposures in an atmosphere of helium would eliminate these bands, but would also alter the excitation in the spectrum under investigation.

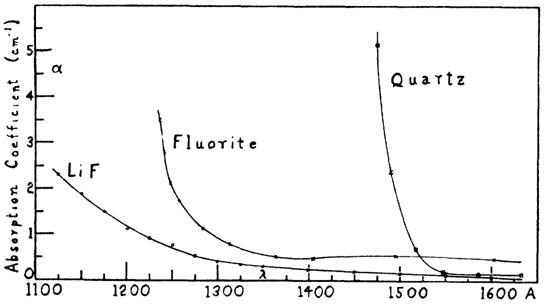

FIG. 1. Absorption coefficients in quartz, fluorite, and lithium fluoride as a function of wave-length. (Schneider, 1934, 1936, and Powell, 1934.)

spectrum. In spite of the limited resolving power of this method, it is clear that the continuous absorption of oxygen from λ1100 to at least λ300, mentioned by Ladenburg, Van Voorhis and Boyce, has superposed on it many absorption bands. These bands include many of those found by Price and Collins. It is clear from Schneider's results that even the "window" from λ1300 to λ1100 has absorption bands scattered through it.

III. TRANSMISSION OF SOLID MATERIALS

THE number of solid materials usefully transparent in the vacuum ultraviolet is extremely limited. For practical purposes two materials are available: fluorite and lithium fluoride. For a very limited wave-length range crystal quartz may also be used. Different samples of each of these three materials show wide variations in their spectral transmission curves. The transmission of quartz has been investigated by Scheibe (1929) and by Powell (1934). For very thin windows, good samples of crystal quartz may be used down to λ1450. The greater thickness required in lenses and prisms seriously restricts the use of quartz, since even at λ1860 one centimeter of quartz absorbs from 25 to 30 percent of the radiation passing through it. Fused quartz does not seem as transparent as crystal quartz, but the wide variation between individual samples of each must not be overlooked.

Until recent years fluorite has been used almost exclusively. Schneider (1934) and Powell (1934) have investigated its transmission. Since light is also lost at reflection at each surface of the sample under investigation, measurements must be made on several samples, of different thickness, cut from the same original piece of fluorite. The true absorption coefficient μ is determined from the formula

$$I = I_0(1-r)^2 e^{-\mu x},$$

where I_0 is the intensity of the incident radiation, I the intensity of the transmitted radiation, r the fractional loss of light at the surface which includes reflection[4] and any other surface losses of light (at each surface), and x is the thickness of the sample. Schneider used photographic photometry and Powell used a photoelectric method. Their results (on the same samples) were in substantial agreement. Schneider's values of μ (in cm^{-1}) are given as a function of wave-length in Fig. 1. It will be seen that the absorption coefficient increases very rapidly below λ1250 and a sample of fluorite is indeed good if it shows appreciable transmission at λ1230. Leifson (1926) was able to observe the very intense λ1215 line of hydrogen through two thin windows from an exceptionally good sample of fluorite. In ordinary use the transparency of fluorite seems a permanent property, although Palmer (1934) reported that where strong, short wave-length, ultraviolet radiation emerged from a fluorite window into air, a surface film formed on the fluorite. This film absorbed strongly between λ1500 and λ1200. Groth (1939) reports no similar phenomenon in fluorite strongly irradiated by the xenon lamp.

In recent years large crystals of lithium fluoride have become available through the work of Schneider (1936) and Stockbarger (1936). By means of a technique used by Bridgman (1925), large homogeneous crystals are formed when the melted material is cooled slowly and uniformly in a definite temperature gradient. The crystals have interesting optical properties in that lenses made from them are very nearly achromatic over the range of the visible spectrum. If extreme precautions are taken in the purification of the material, windows and thin lenses may be obtained which are transparent somewhat below λ1100. The transmission of lithium fluoride has been investigated by Schneider (1936) and Groth (unpublished). Schneider's values of the absorption coefficient as a function of wave-length are

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[4] The reflecting powers of fluorite and quartz in the vacuum ultraviolet have been measured by Tousey (1936, 1939, 1940) in a study of the optical constants of those substances.

given in Fig. 1. The absorption coefficient is everywhere less than that for fluorite.

Lyman (1935) has developed a most ingenious method for testing the transmission of lithium fluoride without the use of a vacuum spectrograph. As mentioned in the previous section, radiations of wave-length between λ1100 and λ1300 can travel several centimeters through air. Such radiations from a spark in air between metallic electrodes (the "Entladungsstrahlen" of Wiedemann and Schmidt (1895)) are allowed to fall upon a thermoluminescent detecting plate. Pieces of lithium fluoride to be tested are placed on the surface of the plate. Upon heating the plate in the dark subsequent to exposure, thermoluminescence occurred over those portions of the plate directly exposed to the rays. It also occurred a little less strongly on those portions of the plate which had been covered with good samples of lithium fluoride, but not from a region which had been covered with a good piece of fluorite. Lyman concluded that the thermoluminescent detector was sensitive to radiation in the range from λ1100 to λ1250. Subsequent experiments with a vacuum spectrograph showed that the sensitivity of the thermoluminescent detector began abruptly at about λ1300 and extended at least to λ900. More details of the thermoluminescent method of detection will be given in a later section.

Lithium fluoride has one serious weakness. Under exposure to intense radiation, as well as to electron bombardment from a gas discharge, discoloration occurs which is accompanied by a gradual shift of the absorption limit by as much as several hundred angstrom units. Schneider (1937) has studied this effect. If the discoloration is not too marked it may be removed by heating the crystal. The discoloration occurs chiefly at the surface of the crystal and Stockbarger finds that this portion can generally be removed by repolishing.

Laird (1920, 1927) found that a celluloid film 300 to 400A thick transmitted 50 to 20 percent of the radiation from λ1700 to λ900, but not much over 5 percent below λ900. She also found that silver foil 2000A thick transmitted strong lines down to λ900. O'Bryan (1932) investigated the absorption in celluloid between λ1000 and λ300. Films 60 to 400A thick were prepared by dropping a dilute amyl acetate solution of celluloid upon a water surface. Small portions of the film were removed from the water on aluminum frames. The thickness of each film was computed from the concentration of the celluloid in the amyl acetate solution, the amount of the solution dropped on the water surface and the area over which the film spread on drying. Films of this thickness were black by reflected light. O'Bryan found that the degree of "blackness" was in qualitative agreement with the computed thickness and suggested that measurements of the transmission of visible light by the films might prove a fair index of their thickness. Films thick enough to show any colors by reflected light absorbed all energy between λ1000 and λ300. For a celluloid film 100A thick, O'Bryan tabulated the transmission which ranges from 79 percent at λ300 to about 30 percent at λ900. At still longer wave-lengths (beyond the range investigated by O'Bryan) the transmission again increases. The films deteriorate in a few days in high vacuum and in a few weeks in air. Their use as windows is limited to a pressure difference of a few millimeters of mercury, but they have served considerably as supports for thin evaporated films of solid materials in the investigation of the absorption spectra of such substances.

Lyman (1928, p. 66) and Bomke (1937, p. 18) discuss the transparency of a number of other materials, but none of them seems comparable with fluorite or lithium fluoride.

IV. Reflecting Power of Gratings and Mirrors

G. B. Sabine (1939) has measured the reflecting power from λ4000 down to λ450 for glass and for evaporated films of a number of metals: aluminum, antimony, beryllium, bismuth, cadmium, chromium, copper, gold, iron, lead, magnesium, manganese, molybdenum, nickel, palladium, platinum, silver, tellurium, titanium, zinc, and zirconium. The reflectivities (given graphically as a function of wave-length) are not necessarily those of a pure surface free of any adsorbed gas, but represent the surface conditions of such mirrors as obtain ordinarily in an evacuated system. Above λ1200 aluminum is definitely the best reflector, below λ1000 platinum is the best.

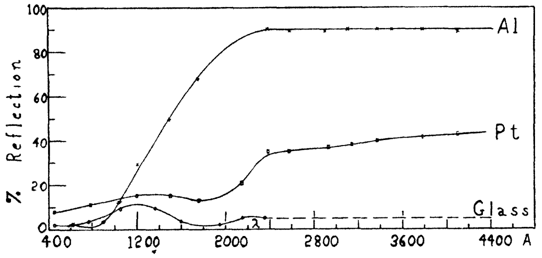

FIG. 2. Percent reflection of aluminum, platinum and glass as a function of wave-length. (G. B. Sabine, 1939.)

Glass is somewhat inferior to platinum throughout the whole range tested. Figure 2 gives Sabine's data for glass, aluminum, and platinum. Sabine's measurements were made with light incident at about 18° from the normal.

Glass has a great advantage over most metal surfaces in its freedom from tarnish. Its reflecting power may be considerably diminished by adsorbed films, particularly of oil and grease, but these may easily be removed by an organic solvent or by stripping off the nitrocellulose film left by the evaporation of collodion. Speculum metal, frequently used for gratings, must be protected against mercury vapor and against any vapors containing sulphur (as from some rubber gaskets and from some stopcock greases). Under proper conditions of evaporation, thin aluminum and platinum films deposited on glass gratings (and mirrors) would be expected to be reasonably permanent and free from tarnish. But such techniques are so recent that not much experience is yet available as to the permanence of the surfaces under vacuum conditions.

Gratings ruled directly on aluminum have been very useful in other regions of the spectrum and should be tried in the region from λ1850 to λ1000. Gratings ruled on a relatively soft metal surface (such as speculum or aluminum) have the advantage in that it is possible to control the groove form and so concentrate energy into a particular order of the spectrum. It seems impossible to do this on glass, though R. W. Wood has been able to improve the intensity of spectra from glass gratings by etching with hydrofluoric acid after the ruling has been done. Gratings ruled on glass seem useful in preliminary experiments with evaporated films, but if it should be possible to deposit a thin film of platinum over a grating ruled on a softer substance one could attain at the same time the advantages of the controlled groove form and the higher reflectivity for the region of wave-lengths less than λ1000.

Stenström (1919) showed, from deviations from the Bragg law for x-ray reflections from crystals, that the refractive index of most solids for x-rays is slightly less than unity. A. H. Compton (1923) demonstrated that a beam of x-rays falling nearly tangentially on a polished metal plate undergoes total reflection at the surface. Gratings have been used most successfully at grazing incidence, both in the ordinary x-ray region and in the region of the vacuum ultraviolet of wave-lengths less than λ1000. Gratings have been used at grazing incidence for wave-lengths longer than λ1000 and appear to have improved reflecting power, but it is not certain at what upper limit of wave-length the phenomenon of total reflection ceases for any particular angle of incidence. O'Bryan (1931) has pointed out that groove form and surface smoothness as well as reflecting power govern the efficiency of a grating, particularly when used near grazing incidence. He concluded that the etched glass grating is more suitable for grazing incidence, but that the speculum grating or a lightly ruled glass grating is to be preferred for use nearer normal incidence. Other aspects of the choice between normal incidence and grazing incidence for gratings will be discussed in a later section.

V. PHOTOGRAPHIC TECHNIQUES AND OTHER METHODS OF DETECTION

EVEN before the vacuum portion of the ultraviolet is reached, photographic difficulties arise. Gelatine in the photographic emulsion absorbs radiation of wave-lengths shorter than about λ2265. This enormously reduces the sensitivity and contrast of the plates, since the radiation penetrates only a very thin surface layer of the emulsion. To overcome this difficulty, Schumann first tried pure silver bromide deposited directly on a glass plate. He found this arrangement sensitive, but impermanent. The silver bromide film was apt to float away from the plate during the process of fixing. Next he tried depositing a layer of silver bromide on top of a layer of gelatine. This gave improved sensitivity and contrast as well as greater mechanical stability. After a number of further experiments, Schumann

(1901) adopted a procedure which was little changed for many years. In principle it gives an emulsion of silver bromide containing just a minimum amount of gelatine. The process of preparation of the emulsion is somewhat elaborate and must be carried out with considerable care, if the sensitivity of the plate is not to be impaired. The emulsion as finally coated on the plates is very easily brushed off. The plates must be handled with great care, both before use and, unless they are varnished, even after processing.

Details of the technique of preparation of Schumann plates would be out of place here. Schumann gave elaborate details and these have been discussed by Lyman (1928). Hopfield (1922) and Hopfield and Appleyard (1932) have advised certain modifications of Schumann's procedure, particularly that of depositing the Schumann emulsion on top of the gelatine (freed of silver bromide) of an ordinary commercial photographic plate or film. While some investigators still prefer to prepare their own Schumann plates or films, many have found it easier to buy them from Hilger in England or from Agfa in Germany.

Duclaux and Jeantet (1921) made two innovations. In the first they proposed the "Schumannization" of ordinary photographic plates by treatment with sulphuric acid. This process eats away most of the gelatine in the surface layer of the emulsion and leaves it rich in silver bromide. The method seemed successful but has not come into general use since the resulting emulsion is very fragile. A number of other reagents were tried, including an enzyme for the digestion of the gelatine, but the sulphuric acid was the most satisfactory.

The second method proposed by Duclaux and Jeantet has been used extensively. In it a thin layer of fluorescent oil is deposited over the surface of an ordinary photographic plate prior to the exposure and is removed prior to development. A considerable number of types of oil may be used. If the plates are to be used in a vacuum it is better to choose an oil with a relatively low vapor pressure. For efficiency, the wave-length of the fluorescent radiation emitted by the oil should match that of the maximum sensitivity of the photographic plate used. Duclaux and Jeantet did not themselves test oiled plates in the vacuum ultraviolet. This was first done by Lyman (1922), who reported them sensitive at least as far down as λ500.

Photographic plates for the detection of mass rays must have somewhat similar properties in order that they may record the charged particles which penetrate only a short distance into the emulsion of an ordinary photographic plate. Ilford, Ltd., in England prepared a special plate for the isotopic investigations of Aston (1931, 1937). It contains an amount of gelatine intermediate between the amounts present in the emulsions of ordinary photographic plates and in the Schumann emulsion. By means of an undisclosed manufacturing process a high density of silver bromide grains is obtained at the surface of the emulsion. This plate is commercially available in three grades, Q1, Q2 and Q3, listed in order of increasing speed and grain size.

Eastman spectroscopic plates may now be ordered with special sensitization for the extreme ultraviolet. The emulsion is coated at the factory with a fluorescent material, which must be washed off in ethylene chloride previous to development. This plate has much the same properties as an oiled plate but is more convenient and more uniform. This sensitization is usually added to the O-type Eastman spectroscopic plate, in the various grades of speed and grain size. It is perfectly possible to combine this ultraviolet sensitization with other types of Eastman spectroscopic plates if it is ever necessary to record on the same plate radiations from two widely differing wave-length ranges. Such a problem might arise if one wished to make direct interferometric comparisons between the red cadmium line and lines in the vacuum ultraviolet.

Comparison of the properties of these various plates is not quite as simple a matter as listing their threshold sensitivities at various wave-lengths, since for many spectroscopic purposes gradation is more important than threshold sensitivity. A very interesting study of the properties of various types of plates has been made by Hunter and Pearse (1938) for the wave-length range λ2500 to λ2000. They find that certain plates with very high threshold sensitivity in this region have extremely low maximum density and hence have no scope for contrast. This is particularly true in that spectral range for the ordinary type of photographic emulsion. This is to be expected in view of what has been said about the opacity of gelatine and the shallow penetration of the short wave-length radiation into ordinary emulsions. It is unfortunate that a similar systematic comparison has not yet been made at still shorter wave-lengths. The experience of the present writer is limited to Hilger Schumann, Ilford Q, and, in recent months, Eastman ultraviolet sensitized plates. The first named of these has undoubtedly the highest threshold sensitivity, but is the most expensive and the least uniform. At the moment both Ilford and Eastman plates are being used. The light sources in use have not been suitable for quantitative comparison between the two plates. Pending such comparison, present indications suggest that both are satisfactory for general purposes. Skinner and Johnston (1937) have used Hilger Schumann, Ilford Q and oiled plates in soft x-ray investigations in the range λ300 to λ100. They find the Q plate is 100 times faster at λ200 than oiled plates in this range and comparable with the Schumann plate. They further state that, because of gelatine absorption, the sensitivity of the Q plate at λ400 is only about 10 times that of an oiled plate.

With short focus instruments, the plate must have high resolving power if the full resolution of the grating is to be utilized. For this particular property the Schumann plate is outstanding. Bowen has measured lines on a Schumann plate 0.01 mm apart. The resolving power of the Ilford Q plate is a little smaller. Oiled plates would be expected to have a considerably smaller resolving power. The layer of fluorescent material coated on Eastman ultraviolet-sensitized plates is very thin and would not be expected greatly to decrease the resolution of the emulsion upon which it is coated. If the highest resolution is required on Eastman plates for a short focus instrument, the Research Laboratory of that company should be consulted as to the best emulsion currently available to which the ultraviolet sensitization can be added. The Eastman ultraviolet plates so far used by the present writer have O-type emulsions. They seem to have adequate resolution for a 2-meter focus grating with 90,000 lines, ruled 30,000 lines to the inch, but they cannot compete with the Schumann-plate resolving power quoted above.

Harrison (1925) tested oiled plates and films for uniformity of response and found they were far superior to Schumann plates for photometric purposes. Harrison and Leighton (1930, 1931) found that the characteristics of the oiled plate are constant over the wide spectral range in which radiation is totally absorbed by the oil and are those of the original emulsion for the wave-length of the fluorescent radiation coming from the oil. Furthermore, over a wide wave-length range, the quantum efficiency of the fluorescence is constant. Here indeed is a fortunate situation, almost unique, in that the methods of heterochromatic photographic photometry in the vacuum ultraviolet appear to be considerably simpler than those in the more accessible regions of the spectrum.

Photoelectric detection of radiations in the vacuum ultraviolet region of the spectrum is also somewhat simpler than for longer wave-lengths, since at these shorter wave-lengths most metals give off photoelectrons and investigators are not restricted to alkali metals. A proper choice of metal makes the cell insensitive to radiations in the visible and near-ultraviolet portions of the spectrum. Platinum is often used. When thoroughly outgassed its photoelectric threshold comes at λ1962. When platinum has not been outgassed this threshold varies from λ2800 to λ3000. A table of values of photoelectric threshold for a number of metals, and under different surface conditions, has been given by Hughes and DuBridge (1932, p. 75). Such photoelectric detection in the vacuum ultraviolet was used in the early experiments of Lenard (1902), Franck and Hertz (1914, 1916) and others. These early experiments on critical potentials did not always distinguish between ions collected at the plate and photoelectrons ejected from this plate by short wave-length radiation impinging upon it. Davis and Goucher (1917) and others devised combinations of electrodes to distinguish between the two effects. Of particular interest in our present discussion is the experiment of Olmstead and K. T. Compton (1923). These investigators determined the "radiating potentials" of atomic hydrogen, the energies (in electron volts) necessary to excite successive members of the Lyman series of hydrogen. The lines in question lie approximately at λ1215, λ1025, λ972, λ949, etc. Olmstead and Compton detected these radiations by the photoelectrons which were ejected from a platinum plate. To assure complete dissociation into atomic hydrogen, excitation took place inside a tiny furnace at 2800°K.

Photoelectric detection of total undispersed radiation in the vacuum ultraviolet has been comparatively common, but its combination with a spectrograph has been seldom used. Powell (1934) has used the combination in his investigations of the transmission of fluorite and of quartz, and more recently Preston (1940) has used it in measurements of the absorption coefficient of certain gases for λ1215.

Pfund (1926) has used the thermopile to measure radiation in a study of reflecting power of materials in this wave-length region, but without spectroscopic dispersion.

The photochemical formation of ozone from molecular oxygen by the action of Schumann radiation has been used by a number of investigators to measure the intensity of the radiation. The quantum yield of this reaction is known to be 2. The radiation falls into a cell containing oxygen in sufficient amount to insure complete absorption. The gas flows steadily through the absorption cell and into the appropriate chemical equipment for the quantitative estimation of ozone. This is the most direct method available for determining intensity in terms of quanta per second. We will return to the subject of photochemical reactions in a later section.

Mention has already been made of thermoluminescent detection of radiations in the vicinity of λ1200. Following a process described by Hoffmann (1897), Lyman (1935) prepared a mixture of calcium sulphate, a few percent of manganese sulphate and a little water. This was evaporated, the residue ground to a powder, mixed again with a little water and flowed on copper strips of suitable dimensions. After evaporation of the water, the copper with its coating was heated to redness for a few minutes. After the plate is cooled, it will store up the energy of impinging short wave-length radiations, releasing this energy as visible light when the plate is warmed. As already stated, Lyman found that the long wave-length limit of sensitivity of the thermoluminescent plate is λ1300. The exposure to short wave-length radiation can take place in daylight. The luminescence may subsequently be observed in the dark by heating the copper strip on an electric hot plate to 180°. After the luminescence has occurred the plate is again ready for use. To secure a permanent record, a photographic plate may be placed one millimeter from the calcium sulphate surface while it is heated, but the photographic plate should not touch the calcium sulphate surface.

Lyman's experiment with a spark gap and a thermoluminescent plate of the type just described makes a very striking lecture demonstration.

VI. Spectrographic Design

IMPORTANT factors governing the design of vacuum spectrographs include the requirements of spectral range, dispersion and resolution, flexibility and convenience of operation, and the limitations as to available prism or grating, as well as the old and familiar item of cost. Three types of instrument are available: prism spectrograph, normal-incidence grating spectrograph and grazing-incidence grating spectrograph. A typical example of each will be discussed in turn, primarily as optical instruments, and then a few remarks will be added about the vacuum systems that must enclose them.

A prism instrument is useful for work in the Schumann region, that is down to the limit of transparency of fluorite (λ1250) or of lithium fluoride (λ1200–λ1100 depending on the sample). A convenient form has been described by Cario and Schmidt-Ott (1931) and has been widely used. A small 60° fluorite prism was used with fluorite lenses 8 mm in diameter and 100 mm in focal length. Such an instrument is entirely adequate in the Schumann region for the study of simple line spectra and absorption bands. It does not have adequate resolution to study complex atomic spectra or the rotational structure of the bands of diatomic molecules, but there are many spectroscopic observations for which it is most satisfactory, including intensity measurements in simple emission and absorption spectra. Larger prism instruments have been built, but do not have the primary advantages of small size and short time of evacuation. In larger prism instruments, the freedom from high orders of

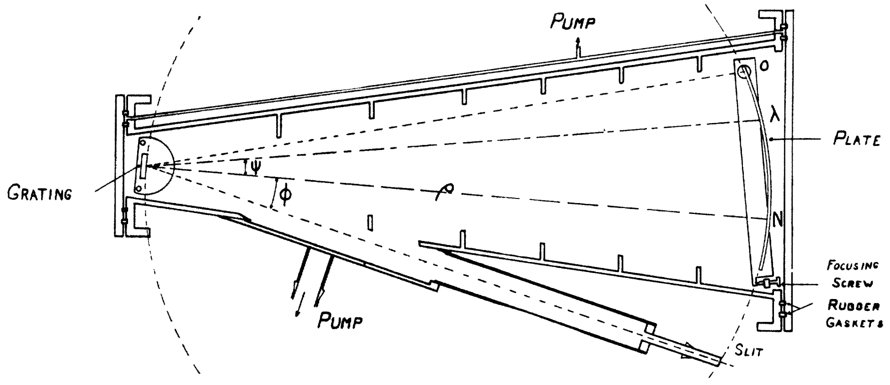

FIG. 3. Normal-incidence vacuum spectrograph ($\phi = 13.7°$). (K. T. Compton and J. C. Boyce, 1934.)

shorter wave-length does not usually outweigh the larger available range of wave-length of a grating instrument and its more nearly constant dispersion.

The theory of the concave grating is well known and will not be repeated here. It has been summarized by Kayser (1900) and particular aspects of it have been discussed more recently by Dieke (1933) and by MacAdam (1933). In the customary arrangement of the Rowland circle, the slit, grating and plate all lie on a circle the diameter of which is equal to the radius of curvature of the grating. The familiar equation

$$m\lambda = e(\sin\phi - \sin\psi) \tag{1}$$

governs the position of the mth order of wave-length λ. e is the interval between successive lines of the grating (most conveniently expressed in angstrom units), ϕ the angle of incidence and ψ the angle of diffraction. (For this form of the equation ϕ and ψ are taken as positive on opposite sides of the normal.) If s is the distance from the direct image of the slit ($\phi = \psi$) measured along the circumference of the Rowland circle to any particular point in the spectrum, then the linear dispersion $ds/d\lambda$ at that point is given by

$$ds/d\lambda = \rho/e \cos\psi, \tag{2}$$

where ρ is the radius of curvature of the grating. For a grating ruled 30,000 lines to the inch and with a radius of curvature of 2 meters, these two equations have numerical values

$$m\lambda = 8466(\sin\phi - \sin\psi) \tag{1a}$$

and

$$ds/d\lambda = 0.2362/\cos\psi \quad \text{(in mm/A)}. \tag{2a}$$

It will be noted that the dispersion is relatively constant near the normal to the grating, but increases rapidly for large values of ψ. Geometrically, the dispersion at any point on the circle is inversely proportional to the length of the chord drawn from that point to the center of the grating. It is, of course, independent of ϕ, and the value of ϕ may be chosen to bring a particular wave-length to the position giving the desired dispersion. Beutler (1940) has developed a convenient method for finding the value of ϕ appropriate to any given spectral range.

A typical arrangement of normal-incidence grating vacuum spectrograph is that of K. T. Compton and Boyce (1934) illustrated in Fig. 3. The grating, ruled on glass 30,000 lines to the inch, has a radius of curvature of 2 meters. The dispersion (0.2362 mm/A at the normal) and resolution seem adequate for complex line spectra and for the rotational structure of the spectra of diatomic molecules. The instrument can be evacuated with its present pumping system (200 liters/sec. self-fractionating pump of Distillation Products, Inc., backed by a Cenco Hypervac mechanical pump) in about an hour. Larger pumps are available to make possible equally rapid evacuation of spectrographs of considerably larger size. Present spectrographs above the 3-meter size usually must sacrifice wave-length range to gain higher dispersion. But larger instruments can have great advantages in the precise determination of wave-length standards and in the study of the rotational structure in the spectra of polyatomic molecules (Duncan and Harrison, 1936). In the instrument illustrated in Fig. 3 a single photographic plate 24 inches long covers the range from the direct image of the slit ($\phi=\psi$) to λ2500. Actual spectra have been observed down to a little below λ300. It may be noted that the angle of incidence was chosen as 13.7° on the basis of the wave-length range desired when the spectrograph was designed in 1929. The subsequent investigation by Dieke (1933) has shown that the angle of incidence of 13° gives the minimum amount of astigmatism. It is very convenient in adjusting the spectrograph to have the direct image fall on the plate. However it would seem worth while, following the design of Simeon (1923), to add a second slit at the slightly larger angle of incidence of 22.2°. An alternate spectral range from λ1200 to λ3700 would then be available at the same plate position. It would be advantageous to be able to photograph the Schumann region simultaneously in both first and second orders in this new range and to be able to shift from one spectral range to the other without changing any optical adjustment. A number of normal-incidence vacuum spectrographs have been constructed for gratings of 1-meter radius of curvature. There are some difficulties in obtaining glass plates able to withstand the necessary focal curvature of 50 cm. With still smaller instruments, one is forced to use films and other difficulties arise in connection with the ruling of gratings on a surface of very short radius of curvature.

The grazing-incidence grating vacuum spectrograph has been used extensively in a number of laboratories, but notably at Upsala. Among the several constructed there the earliest and latest models merit mention. Ericson and Edlén (1930) described a spectrograph constructed by Siegbahn. The instrument had an angle of incidence of 80° on a grating of 1-meter radius of curvature ruled 571 lines/mm and was effective down to λ75. Recently two nearly identical instruments have been constructed for gratings of 5-meter radius of curvature. One is used for soft x-ray investigations and has been described by Siegbahn and Magnusson (1935). The other has been used by Edlén (1936 and subsequently) in his investigations of the spectra of very highly ionized atoms. The grating has 37,440 lines, ruled 576 lines mm. The angle of incidence ϕ is 86°. The long wave-length limit of the plate is λ200 and spectra have been recorded down to about λ40. In another instrument, described by Tyrén (1936), the angle of incidence was 89°. With this extreme angle Tyrén (1938) observed Fe XVII lines at λ12.1. Notable among the grazing-incidence instruments constructed elsewhere is that of Kruger (1933), in which a grating with a radius of curvature of 21 feet was used.

The gratings used at Upsala have different spacings and different radii of curvature from the grating used in the particular example of normal-incidence instrument illustrated in Fig. 3. To make a more exact comparison, Fig. 4 has been drawn to the same scale to illustrate the use of a 30,000 lines/inch grating of 2-meter radius of curvature at an angle of incidence ϕ of 80°. One numerical comparison may be in order. In the (nearly) normal-incidence instrument (Fig. 3, $\phi=13.7°$) the distance from the direct image to the position of the first order of λ500 is 119 mm and the dispersion at λ500 is 0.240 mm/A. In the particular illustration of the grazing-incidence arrangement (Fig. 4, $\phi=80°$) the same spectral range would cover 426 mm of plate and the dispersion at λ500 would be 0.625 mm/A. Since high orders of spectra are strong with grazing incidence and may unduly complicate observations at longer wave-lengths, in actual practice the angle of incidence should be only great enough to obtain total reflection for the shortest wave-length to be reached. This may vary with individual gratings. Edlén (1934) quotes a particular speculum grating that could be used at normal incidence only down to λ320. At $\phi=60°$ it could be used to λ160, at 80° to λ75 and at 84.6° to λ53.

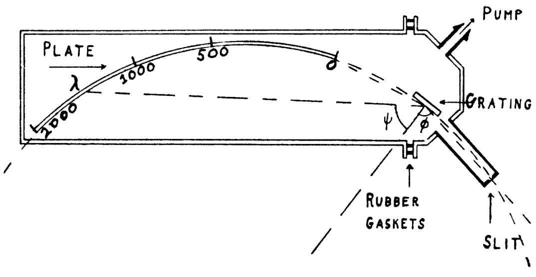

FIG. 4. Grazing-incidence vacuum spectrograph ($\phi=80°$) (schematic).

Investigations by Mack, Stehn and Edlén (1932), Bowen (1933) and Anderson and Mack (1934) have shown that the resolving power of a concave grating decreases with increasing angle of incidence. For nearly grazing incidence there is an optimum grating width for maximum resolving power and intensity. This depends on the angle of incidence, radius of curvature, grating space, wave-length and order of spectrum. A convenient graph for finding the optimum width has been given by Mack and Stehn (1933), but the calculations of Bowen show that a somewhat wider grating may be used if the plate is displaced slightly from the Rowland circle. The most complete and rigorous treatment is by Anderson and Mack. These aberrations of the concave grating peculiar to large angles of incidence prevent the use under these conditions of the outside orders of the spectrum between the grating and the direct image. When a large grating, used at grazing incidence, is masked to comply with this requirement there is a dual benefit. Not only is the resolution improved, but a type of ghost peculiarly haunting grazing incidence is banished. Sometimes it is necessary to mask some of the top and bottom of the ruled surface of the grating as well as the sides as these ghosts seem to come from the outer edges of the ruled surface. The adjustment of a grazing-incidence instrument has been described in detail by Rathenau and Peerlkamp (1935).

Normal-incidence and grazing-incidence spectrographs each possess certain exclusive advantages. In the Schumann region the more nearly linear dispersion and the economy of light due to less astigmatism both definitely favor the normal-incidence instrument. Below λ600 the far greater efficiency of the grating at grazing incidence definitely favors that type of instrument and below about λ300 it alone will operate. From λ1200 to λ600 is a region in which both types are useful. In that region, if the objective is precise determination of wave-length standards, the normal-incidence instrument has the advantage that light is more nearly normally incident on the photographic plate and the wave-length scale is little distorted by small irregularities in the bending of the plate. If the objective is the observation of faint lines, the greater intensity is to be found in this spectral region with the grazing-incidence instrument. It would appear that the normal-incidence instrument is more satisfactory for the wave-length range in which molecular spectra are likely to be studied for rotational structure. It should be pointed out that within the wave-length range assigned to grazing-incidence instruments, there is still a considerable variation in the optimum angle of incidence. This may require two instruments or two settings of one instrument. Edlén (1934) has described a spectrograph with interchangeable slit mountings to give angles of incidence of 70° and 80°.

Widely different housings have been used to enclose the optical system in vacuum spectrographs. A few general remarks may be in order, without going into details of design. The housing should be as simple as possible and all seams or joints should be sufficiently accessible to be tested separately, if leaks should develop. A comparison of Figs. 3 and 4 will show that for larger angles of incidence it is necessary to evacuate a smaller area within the Rowland circle. While the volume to be evacuated within a grazing-incidence instrument is thus somewhat smaller, it does not necessarily mean that it takes up less room in the laboratory. In this type of instrument it seems most convenient to mount the grating and the plateholder on a girder, so that most of the housing may be rolled away from around it. This requires a track about twice as long as the optical part of the instrument. In any type of instrument the housing should have generous inside clearances to give ample range for adjustment or for unexpected replacement of optical parts by others of slightly different dimensions or focal properties. Optical adjustments should have adequate scales, so that settings may be repeated exactly. This is important because it is often necessary to evacuate the instrument for each separate test in the process of focusing. It should be possible to make all adjustments without reaching to awkward positions within the spectrograph. It should be possible to remove the grating for cleaning and to replace it with a minimum number of readjustments. The slit must be readily accessible for cleaning and for adjustment, if possible without loss of vacuum in the body of the spectrograph. Adjustment of slit width and rotation of the slit to secure parallelism with the lines of the grating are both extremely important for maximum resolving power. These two adjustments should be independent of each other.

The slit width adjustment should be adequate for settings down to a few thousandths of a millimeter. It is usually necessary to meet all of these requirements for slit adjustment within a small space in order that the tube containing the light source can be attached close to the slit.

With many light sources, and in particular with the vacuum spark, the slit is sputtered with the material of the electrodes. With the vacuum spark the slit requires frequent and vigorous cleaning. Bowen has found it very advantageous to make all slit jaws of Stellite (a tungsten-nickel-cobalt alloy) as this can safely be cleaned regularly with any of the common concentrated acids. It is also very hard and will stand vigorous mechanical cleaning as well. Slit jaws of this material have been used by Bowen for years and apparently last indefinitely. Those of other materials require frequent replacement.

While a valve is worth while to separate the slit and light source from the body of the spectrograph, it hardly seems necessary to provide an air lock by which the plate can be removed and replaced without loss of vacuum, at least in a 2-meter instrument. It is very useful to provide a plate wide enough so that a half-dozen exposures can be made on a single plate. An external mechanical control of the type mentioned by Bomke (1937, p. 37) is useful for moving the plate between exposures. Ample vacuum gauges, ionization and thermocouple as well as McLeod, soon repay their cost by the time they save in locating any vacuum troubles that arise. A gauge in the fore-vacuum provides a useful check in the operation of the diffusion pump. Cyclotron vacuum systems have used a thermocouple gauge for this purpose.

VII. Light Sources

LIGHT sources for the investigation of emission spectra in the vacuum ultraviolet are not very different from those suitable for use at longer wave-lengths. It is only necessary to specify that the radiation be able to traverse the region of space immediately surrounding the source without too much absorption by the gases or vapors present there. In the case of arcs or sparks, normally operated in air at atmospheric pressure, it is necessary to replace the air by a gas transparent at shorter wave-lengths. As already mentioned, this technique was introduced by Selwyn (1929) and further refined by Shenstone (1938). Nitrogen, argon, and helium are suitable according to the wave-length range desired, but if the monatomic gases are used the characteristics of the discharge may be altered considerably. Data on the transparency of these gases have already been given in Section II. Another problem is encountered in the investigation of the spectra of ionized atoms in the wave-length region of the absorption by the corresponding neutral atom. This difficulty is minimized by reduction of the density of the absorbing atoms, either by dilution in a gas or vapor transparent in this region, or by operation at a lower total pressure.

If it were possible to indicate, by one or more references, where information might be obtained about spectroscopic light sources in general—and then to modify this information to apply it in the region of the vacuum ultraviolet—this section could be most brief. But such information is handed down mostly in the oral traditions of spectroscopy or, when written, it is apt to be entirely empirical. At the risk of restating what is supposed to be common knowledge, an attempt will be made to give a little of the general background about the mechanisms for the excitation of spectra and against this background to outline light sources suitable for the excitation of various spectra.

Atoms and molecules may radiate light whenever they possess excess energy. The probability of emission of this radiation has widely differing values, depending on the state to which the atom (or molecule) has been excited. In some states, this probability is so high that radiation will almost certainly occur in the brief time in which the atom or molecule remains undisturbed between collisions. In other (metastable) states, this probability for radiation is very low and the radiation is exceedingly unlikely to take place, under laboratory conditions, prior to some collision which will relieve the atom or molecule of its excess energy. Apart from nuclear processes which may give rise to the emission of gamma-rays or of x-rays, an atom or molecule may receive energy in four ways: (1) by collision with an electron of sufficient kinetic energy (collisions of the first kind), (2) by absorption of radiation of suitable frequency, (3) in collisions, from other atoms or molecules which possess appropriate amounts of excess energy (collisions of the second kind), (4) by thermal excitation, in which a share of the internal energy of the system goes to excitation of some of its component atoms or molecules. It should be pointed out that all cooperate in thermal excitation. The excitation can be considered as thermal when all the processes are in sufficient equilibrium to justify a thermodynamic rather than an individual treatment. In flame spectra and in furnace spectra, (4) is the means of excitation. In fluorescent spectra, (2) plays the leading role. But for most sources, where energy is supplied electrically, (1) is the primary mechanism even if sometimes modified by the other processes.

The general properties of electrical discharges in gases have been discussed in these Reviews by K. T. Compton and Langmuir (1930, 1931) and, more recently, by Druyvesteyn and Penning (1940), and will not be repeated here. Suffice it to say that the amount of excess energy that can be stored up in an atom, by excitation or ionization or both, depends ultimately on how hard and how often atoms can be hit by electrons. How hard an electron can hit an atom depends on the amount of kinetic energy acquired by the electron, as it is accelerated by the electric field and retarded by collisions with atoms. As a result of this contest, the average electron reaches a certain terminal speed which depends on the electric field intensity, the gas density, and the cross section of the atom for collision with electrons of that speed. Repeated blows by electrons, before the atom has time to unload its surplus energy by radiation or by collisions, lead cumulatively to energies considerably higher than those possible in single collisions at the same terminal speed.

Another contest, that between the processes by which an atom gains energy and the processes by which the energy is passed on as radiation or in collisions, determines the statistical partition of the atoms between those in the normal state and those in the various states of surplus energy. This distribution, and the atomic transition probabilities associated with each radiation process from each excited state, together determine the spectrum of the radiation emitted. In mixtures of gases or vapors, whenever the pressure is sufficient to make collisions between molecules more frequent than collisions with the walls of the containing vessel, the spectrum is mainly that of the element with the lower excited states. This occurs for two reasons: Collisions (of the first kind) with these atoms limit the terminal speed of the electrons and collisions (of the second kind) quickly transfer the energy when an atom with the higher excited states happens to receive it. Metastable states are most important stepping stones in the processes of cumulative excitation and are most effective for storing energy pending its transfer in collisions of the second kind. Metastable states occur in many atoms (and molecules) and are particularly important in the inert gases, mercury, and in both molecular and atomic nitrogen.

Before an electrical discharge begins through a gas, the electric field is determined by geometrical considerations and by the applied difference of potential. Once the discharge starts, this field distribution is considerably modified by concentrations of positive ions. (Even at the high frequencies of an oscillatory discharge, ion concentrations play a part in determining the field distribution.) A sheath of ions, forming near the cathode, marks the edge of the so-called cathode fall. If the discharge is an arc, the difference of potential across the cathode fall is of the order of tens of volts. If it is a glow discharge, the potential drop across the cathode fall will be measured in hundreds of volts. Whether the discharge operates as an arc or as a glow discharge is governed by a combination of factors, among which the constants of the external circuit play a leading part. In the cathode fall of an arc electrons acquire terminal speeds of the order of the ionizing or excitation potential of the gas; in the cathode fall of a glow discharge these speeds are considerably greater. The remaining available space between the electrodes (in addition to that taken up by the cathode fall) is given over to negative glow, Faraday dark space, and positive column, which appear in that order whenever sufficient space is available. The positive column is a region of considerably less electric field than is the cathode fall and, for a given pressure and current, is identical for both arc and glow discharge. The terminal speeds of the electrons are lower here than in the cathode fall and in the early portion of the negative glow, but have a Maxwellian distribution about the average so that a certain fraction of them have sufficient energy to produce ionization. The electron temperature defining this Maxwellian distribution of electron velocities determines the distribution of the excited states produced in single collisions of these electrons with atoms (or molecules) of the gas. For gas pressures of the order of millimeters of mercury there is no equilibrium between the high electron temperature and the much lower gas temperature, but for pressures of the order of an atmosphere this equilibrium is attained and the excitation can be calculated on a thermodynamic basis, following process (4).

K. T. Compton and Boyce (1928) investigated the spectra produced at single collisions in low pressure gases by electrons of known energy. As expected, spectral lines were excited only when the electrons had sufficient energy to excite the neutral atom from its ground state to the appropriate excited state of the neutral atom or directly to the appropriate excited state of the singly ionized atom. For the gases studied, neon, argon, and nitrogen, in no case did the spectrum of the doubly ionized atom appear even though the electrons had adequate energy to excite it. From these observations *if excitation were due only to single collisions* one would expect to obtain spectra of neutral and singly ionized atoms in the negative glow of a low pressure glow discharge, spectra of neutral atoms only in the negative glow of a low pressure arc, and in the positive column of both types of discharge. But in actual fact, spectra are observed for stages of ionization higher than these indicated, both in the negative glow and, less intensely, in the positive column. The obvious conclusion that the excitation is cumulative is supported by the further evidence that this excitation is stronger for those atoms where conveniently placed metastable states provide intermediate "resting places" in the two-stage process. At higher pressures, when thermal equilibrium sets in between the electrons and the gas molecules, conditions are very favorable for cumulative processes.

What has been said so far applies to alternating-current discharges, provided the frequency is not too high, as well as to direct-current ones. In the alternating-current case a negative glow and (if there is room) a positive column are set up each half-cycle in appropriate positions. The light from any point in the tube, as observed by eye or with a spectrograph, is a blend of what comes from the half-cycles of each polarity. When the frequency is so high that the electron path per half-cycle becomes less than the distance between the electrodes, the individual electrons may oscillate back and forth in the tube for many cycles. Such a high frequency discharge will operate even with electrodes external to the vessel containing the gas, provided the oscillating electric field includes the region occupied by the gas. If an oscillating electromagnetic field is supplied from a coil outside the tube, long curved paths are possible for the electrons and an electrodeless "ring discharge" may be maintained even at relatively low frequencies.

After this general discussion certain types of light sources will be mentioned together with the type of spectrum *usually* given by each. It should be pointed out that with unusually low or unusually high ionization potentials there will be exceptional cases not covered by these general statements. We will consider, first, sources where the element under investigation is introduced as a solid substance and is vaporized by the operation of the source. Later we will take up examples where it is introduced as a gas or is vaporized independently of the operation of the source. In each case we will consider examples more or less in the order of the degree of excitation which they produce.

First in order of excitation, for solid materials, is the vacuum furnace of King (1908, 1922). It has been used by King very effectively in selective excitation of groups of emission lines from progressively higher excited states in the neutral atom, which data have been invaluable aids in the analysis of complex spectra. Because the second ionization potential of the rare earths is not very much higher than their low first ionization potential, both first and second spectra of these elements appear in an arc source. The vacuum furnace gives only the first spectrum and permits assignment of other lines in the arc to the second spectrum. The King furnace has not been used for emission spectra in the vacuum ultraviolet region, but has been used by Paul

(1937) to provide vapor for absorption spectra in that region.

Arcs between solid electrodes operating at atmospheric pressure usually give the spectrum of the neutral atom in the positive column of the arc. The excitation here is thermal. For accurate wave-length measurements, light coming from near the electrodes should be excluded from the spectrograph as the higher electric fields close to the electrodes produce a "pole-shift" in wave-length. This is actually Stark effect (Adam, 1932). The higher field close to the cathode usually excites (in the negative glow) the spectrum of the singly ionized atom in addition to that of the neutral atom. The excitation close to the electrodes is not thermal and, from the low value of the cathode fall, the spectrum of the ionized atom appears to be excited cumulatively. For certain elements the line spectrum is complicated by oxide or nitride bands. These may be suppressed by operating the arc in another atmosphere, such as nitrogen (for oxide bands), hydrogen, argon or helium. The use of these gases may increase the excitation over that of arcs in air. Lines excited in arcs at atmospheric pressure have a slight unsymmetrical broadening due to molecular collisions. This pressure shift may be removed by operating the arc at reduced pressures. Such a vacuum arc has been investigated as a source of standard wave-lengths but has not been adopted (International Astronomical Union, 1932). If the arc can be maintained at a pressure low enough that the vapor temperature does not reach equilibrium with the electron temperature, reduced Doppler broadening will improve the sharpness of the spectral lines.

In sparks between solid electrodes we have a transient discharge which later reaches equilibrium as an arc or as a glow discharge. At atmospheric pressure this equilibrium is attained in the order of a thousandth of a second and proportionately faster at lower pressures. In the initial phase of the spark the potential distribution is that determined by geometrical considerations, but this is progressively modified by ion concentrations until the distribution characteristic of one or of the other equilibrium state is reached. The spectrograph integrates light from all phases. The early phase favors "hard hitting" electrons over the whole space between the electrodes, and it is then that the highest excitation occurs. To increase the intensity of this useful phase of the discharge, a condenser is connected in parallel with the gap. This condenser stores electrical charge prior to the initial breakdown and acts as a reservoir for it during the oscillations of the discharge. Other variables remaining the same, increased capacitance increases the number of "hard hitting" electrons and favors higher excitation by cumulative processes. Increased inductance in the circuit, on the other hand, lengthens the period of the individual oscillations. This reduces the current density and, simultaneously, the fraction of time in which the initial field distribution prevails. On both these counts the excitation is reduced. Fowler (1925) discussed the use of variable inductance in the assignment of spark lines to various stages of ionization. Gibbs, Vieweg and Gartlein (1929) described its use in connection with a vacuum spectrograph. The breakdown voltage of the spark is another variable which may be used to control excitation by change of pressure in the atmosphere in which the spark operates. The "softest" spark occurs at the minimum breakdown pressure of the gas (of the order of a tenth of a millimeter of mercury, in most cases), but the increase of breakdown potential secured by going to atmospheric pressure is not nearly as great as is obtained by reducing the pressure to about a ten-thousandth of a millimeter of mercury. "Vacuum sparks" introduced by Millikan and his collaborators have been developed by Edlén (1936) to give the record excitation of eighteen times ionized copper (Cu XIX). Numerical values will be quoted for two extreme cases of spark excitation. Fe II and Fe III are easily excited in a spark between iron electrodes in nitrogen at atmospheric pressure. A 0.1-microfarad condenser is used and charged to about 5000 volts. For Cu XIX Edlén used copper electrodes in a vacuum spark, with a 0.4-microfarad condenser charged to about 50,000 volts. If the electrode vapor pressure (or permanent-gas pressure) is too high to withstand the desired initial voltage, this may be secured indirectly by placing a "harder" spark gap, or even some type of switch, in series with the spark gap under observation.

Not all elements are suitable or available for use as solid electrodes. Solid substances may be added in a hollowed-out core of an electrode of more suitable material, or may be applied in solution to a carbon electrode, or alloyed with other substances, or pressed with silver or certain other metal powders to form pressed-powder electrodes. These latter may be prepared with or without sintering. Care should be taken to avoid compounds or mixtures which will explode under pressure.[5] Vaporization always occurs at the cathode and sometimes at the anode as well. In the carbon arc it is greater at the anode.

The hollow cathode of the Schuler tube has particular usefulness for the full development of spectra of singly ionized atoms (Sawyer and Paschen, 1927). It has been used in the vacuum ultraviolet by a number of investigators, but notably by Shenstone and his collaborators (Shenstone, 1936, 1938; Green, 1939; and others). In this discharge the negative glow is concentrated within the hollow cathode and there is no positive column. The material of the cathode (or material placed inside it) is vaporized by positive ion bombardment. Excitation may be regulated by gas pressure, by the external circuit, and by the choice of gas to be used (helium, neon or argon). Collisions of the second kind play an important part in the excitation process. Green (1939) used a special constant current external circuit for the Fe II spectrum, as did Shenstone (1938) for Pt II. This circuit has subsequently been described by Green and Kuper (1940). The lowest excitation lines of the third spectrum (doubly ionized atoms) often appear in Schuler tube spectra. The excitation of this third spectrum has been increased by Gartlein and Gibbs (1931) by a spark gap, initially closed, in series with the Schuler tube. The gap is opened slightly after the cathode has been heated in regular operation as a Schuler tube.

Materials of appreciable vapor pressure (such as mercury, or even the chlorides of some metals) may be used in an electrodeless discharge, if the discharge is started with an inert gas. The salt is vaporized by the heating of the tube much as sodium is vaporized by the initial neon discharge in the commercial sodium lamp.

If the element under investigation can be introduced as a gas or vapor—provided it does not attack the walls of the tube or any window or electrodes used—excitation is comparatively easy. Frequently electrodes are used with large area to secure high currents and the spectrum of the positive column is observed in a portion of the tube constricted to increase the current density. For the vacuum ultraviolet this portion is usually viewed end-on. Excitation is varied by the external circuit and by the gas pressure. Two numerical examples will illustrate the range of possibilities. Commercial signs use a pressure of neon of about one centimeter of mercury. For small signs a few feet long, power from a 5000-or 10,000-volt transformer, used without a condenser, is sufficient. The spectrum produced is almost entirely that of the neutral atom (Ne I). For the spectrum of four times ionized neon (Ne V), Paul (1939) used a mechanical switch to discharge a one-microfarad condenser through a tube containing neon at an estimated pressure of a hundredth of a millimeter of mercury. A serious limitation in the excitation of the spectra of highly ionized gases is the amount of impurities, principally oxygen and silicon, introduced by the bombardment of the walls of the discharge tube.

Other gas sources are useful. A Schuler tube may be used for the first and second spectra of the gas, provided the current is kept low enough to prevent vaporization of cathode material. An electrodeless discharge is useful for the excitation of second, third and fourth spectra of gases. Some selection of stages of ionization can be obtained by variation in pressure from an optimum value (perhaps a tenth of a millimeter of mercury) for maximum excitation. The general remarks about transparency in the spectral region under investigation, made in the first paragraph of this section, must not be forgotten in connection with gas sources of radiation.

Investigations of absorption spectra in the vacuum ultraviolet require a source of continuous spectrum in this region. A high current discharge in hydrogen gives a continuum extending from the visible down to λ1600. Hopfield (1930) found a similar continuum in helium in the range from

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[5] An introduction to the possibilities of powder metallurgy may be found in the Proceedings of the Conference on Powder Metallurgy, Massachusetts Institute of Technology, 1940.

λ900 to λ600. Beutler (1933) used this helium continuum for his absorption spectra. Lyman (1924, 1928 p. 49) used an impulsive discharge from a condenser through a capillary tube, with an external gap in series to give high breakdown voltage. This produced an uninterrupted continuum from the visible down to λ900. Rathenau (1933) increased the electrical power and extended the Lyman continuum to λ270. He concluded that the excitation is of two kinds. At longer wave-lengths there is the blackbody radiation from the particles ejected from the walls of the tube, but at the shorter wave-lengths it is soft-x-ray continuous radiation resulting from electron impacts in the discharge. The nature of the gas in the tube is unimportant as most of the continuum seems to come from decomposition products of the walls of the tube. The capillary tube naturally has a short life. The usefulness of this source was considerably increased when Collins and Price (1934) modified the technique to provide replaceable quartz capillary linings which could be inserted into a permanent tube.

Finkelnburg (1933) has reviewed the mechanisms by which a gas can give rise to a continuous spectrum.

VIII. WAVE-LENGTH STANDARDS

THE wave-lengths of the spectra of neutral atomic hydrogen and of singly ionized helium may be calculated with very great accuracy. Even the wave-lengths calculated on the basis of the simple Bohr model with circular orbits come very close to those given by more exact treatment. Calculated wave-lengths have been used very extensively as standards in the vacuum region. The best values are given by Paschen (1929) and by Penney (1930). Paschen's values are reproduced for convenience in Table III of Appendix B.

While most satisfactory in preliminary investigations, these calculated wave-lengths of hydrogen-like atoms (Li III, Be IV, etc., may be used at still shorter wave-lengths) are too widely separated for most purposes. The hydrogen lines are apt to be unduly broad for precise measurement. The lines of ionized helium are somewhat difficult to excite and require helium of considerable purity. Bowen and Ingram (1926) proposed as standards a number of lines of C, N, O, and Al between λ1990 and λ599 and determined their wave-lengths by comparison in higher orders against the first order of iron lines in the visible and ordinary ultraviolet regions of the spectrum. Edlén (1933, 1934) used a similar method to obtain standards among the lines of C, O, and Al in the region from λ1371 to λ160. Boyce and Rieke (1935) (and later Webber and Watson (1936)) used the same method, but with higher dispersion, to redetermine some standards (C, N, O, A) in the region from λ1930 to λ580.

All methods involving a comparison between spectra of different orders are liable to a small error. This error arises from differences in line profile in different orders. While this effect might be absent, or much reduced, in an ideal grating, it is a real effect to be guarded against, as the following simple considerations will indicate. When a particular spectral line formed by a concave grating is examined with one side or the other of the grating masked off, it is usually found that the line profile is slightly changed. This may be due to a progressive alteration in groove form which occurred during the ruling of the grating or even to the slight variation in the angle of incidence. The angles of incidence and diffraction vary from one side of a concave grating to the other and the variation of efficiency of each element of the grating with this angle must itself be a function of wave-length. Thus a first order of one wave-length and a second order of half that wave-length, coming to the same position on the photographic plate, would be expected to have slightly different profiles because of the differing "weights" of the contributions to each order from the many elements of the grating. Under favorable conditions with certain gratings this error is negligible, but since a similar error can arise from imperfections of focus it is necessary to know whether or not such an error is present whenever the method of overlapping orders is used in measurements. It is further necessary to check for it every time the adjustment of the grating is changed. This type of error has been known to spectroscopists for many years, but has sometimes been overlooked.[6]

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[6] A second and related type of error is better known. It may arise if the grating is not illuminated in exactly the same way by the source of the comparison spectrum

The possible error due to comparison of overlapping orders can be avoided by a method based on the combination principle and first used by A. Fowler. It may be illustrated schematically as follows. A, B°, C, and D° are spectroscopic terms so placed that the lines $A-B^\circ$, $B^\circ-C$, and $C-D^\circ$ may all be measured (in the same order) with some certain accuracy against secondary standards of wave-length. Then the transition $A-D^\circ$ will occur at a considerably shorter wave-length and can be calculated with a great wave-length accuracy. For example, if the three lines lie in the vicinity of λ5000 (20,000 cm^{-1}) and can be measured with an accuracy of 0.05A (0.2 cm^{-1}), then the fourth line will occur in the vicinity of λ1666 (60,000 cm^{-1}) and can be calculated with an accuracy of 0.016A (0.6 cm^{-1}). Shenstone (1936) has made extensive use of this method in his investigation of the second spectrum of copper. He lists about 95 lines between λ1663 and λ685 which he has observed in the spectrum of a hollow cathode in helium and for which he can calculate wave-lengths by the combination principle. The estimated error for these 95 lines ranges from 0.001A to 0.004A. Shenstone's standard copper lines are listed in Table I of Appendix B. Only a few of these lines appear in a copper spark in nitrogen. Green (1939) has investigated the vacuum ultraviolet portion of the second spectrum of iron, as excited in an iron spark in nitrogen. He finds 110 lines (see Table II of Appendix B) between λ1960 and λ1550 of which the wave-lengths can be calculated by a similar method and with comparable precision. The spark in nitrogen is much easier to operate than the hollow cathode. It would be most helpful if similar standards could be set up, to cover at least part of the copper range, among the lines of some other element which could be excited in a spark in nitrogen.

More and Rieke (1936) compared the standards of Boyce and Rieke and of Webber and Watson against the Cu II standards, comparing lines in the same order of the spectrum. No systematic error of coincidence was found. More and Rieke therefore recommended the use of certain weighted mean values of their own results and those of the two previous investigations. These are given in Table IV of Appendix B. Such mean values have probable errors from 0.002 to 0.005A and should, in general, be regarded as less certain than the copper and iron standards of Shenstone and Green, though for many purposes they are adequate.

MacAdam (1936) attempted to use a reflection echelon for the interferometric determination of standards in the vacuum ultraviolet. He was able to obtain interference patterns for some of the Cu II lines studied by Shenstone and confirmed the calculated wave-lengths. Continuation of MacAdam's work is on the future program of this laboratory but it is realized that the work will be very difficult because of the high orders of interference involved. No other type of interferometer seems suitable for the wave-length range.

For the immediate future it would appear likely that most of the wave-length standards for the vacuum ultraviolet will be determined by the use of the combination principle or, as in the case of an investigation by Edlén now in progress, by successive applications of the combination principle to reach still shorter wave-lengths. Edlén is measuring the spectra of a number of the lighter elements in the range covered by Green's iron standards. Application of the combination principle within the spectrum of these lighter elements will then determine new standards at considerably shorter wave-lengths.

Fullest advantage can be taken of the method based upon the combination principle, if the visible and near-ultraviolet lines used are measured interferometrically. This is, fortunately, the case for many of the copper and iron lines. It is also important that the spectrum used be as free as possible from hyperfine structure.

IX. Atomic Spectra

THE greatest bulk of observational data already obtained in the vacuum ultraviolet is naturally concerned with atomic spectra. A critical bibliography of such data, prepared with the very capable assistance of Dr. Lore Misch, is presented as Appendix C. An earlier bibliography of atomic spectra, in all wave-length ranges, was

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as by the source of the spectrum under investigation. This error is also presumably due to differences in profile of the lines. It can be avoided if the standard lines can be excited simultaneously in the source of the lines under investigation.

published by Gibbs (1932) in these Reviews. Only a few of the papers listed by Gibbs contained data of wave-lengths shorter than λ2000. Our present bibliography is concerned only with wave-lengths below that perhaps arbitrary frontier, and even there omits papers listed by Gibbs when more recent investigations have given the same lines with greater wave-length precision.

Papers have been listed by element and, where possible, by stages of ionization of that element. In addition to the customary reference to author and to place of publication, the number of lines and the wave-length range of the observations are given, and it is generally stated whether or not the lines have been classified into a term system. When available, the latest values of the ionization potential have been included. The papers on emission spectra have been assigned symbols **A, B, C** representing the rating which the present writer gives them on the basis of the number and accuracy of the wave-lengths listed.

The symbol **A** represents an investigation which may be considered as definitive, in that it presents, with adequate precision, such data from the vacuum ultraviolet as are needed from that region for reasonably complete analysis of the particular spectrum. In certain cases, the first spectra of the inert gases for example, only a few lines are necessary to satisfy this criterion, since the energy states of the atom, except the ground state, were all well determined by data from the more accessible portions of the spectrum. Allowance is made for the fact that difficulties in excitation limit the comparable development of the spectra of successively higher stages of ionization. Papers indicated by **B** are considered as a partially complete description of the spectrum in vacuum ultraviolet. In such papers the wave-lengths given are believed to be sufficiently accurate, but the number of lines observed has not been (or does not appear to be) sufficient to complete the analysis of the spectrum. In some cases the lines have not even been assigned to stages of ionization. Papers denoted by **C** are considered as reconnaissance surveys, either because of inadequate dispersion or inadequate standards of wave-length, or both. A paper discussing special features of particular lines is listed without designation.

TABLE I. *Observational data on atomic spectra in emission in wave-length range shorter than λ2000.*

	I	II	III	IV	V		I	II	III	IV	V
1 H	**A**										
2 He	**A**	**A**									
3 Li	**L**	B	B								
4 Be	**A**	**A**	B	B							
5 B	C	**A**	**A**	B	B	13 Al	C	B	B	**A**	B
6 C	**A**	**A**	**A**	**A**	B	14 Si	**A**	B	**A**	**A**	B
7 N	**A**	**A**	**A**	**A**	B	15 P	B	**A**	**A**	**A**	**A**
8 O	B	**A**	**A**	**A**	**A**	16 S	**A**	B	B	B	B
9 F	B	B	**A**	**A**	**A**	17 Cl	C	C	**A**	B	B
10 Ne	**A**	**A**	**A**	C	C	18 A	**A**	**A**	**A**	B	B
11 Na	**L**	B	B	B	B	19 K	**L**	B	B	B	B
12 Mg	C	C	**A**	**A**	B	20 Ca	**L**	C	B	B	B

TABLE I. (*Continued.*)

	u	I	II	III	IV	V		u	I	II	III	IV	V		u	I	II	III	IV	V		I	II	III	IV	V
21 Sc	B	**X**	O	B	B	B	39 Y		**X**	**X**	C	O	B	57 La		**L**	**X**	B	O	O	89 Ac	—	—	—	—	—
22 Ti		**X**	C	C	C	B	40 Zr		**X**	**A**	**A**	B	O	72 Hf		O	B	O	O	O	90 Th	O	O	O	B	O
23 V		C	**A**	C	B	B	41 Cb	C	O	O	B	**A**	B	73 Ta		O	O	O	O	O	91 Pa	—	—	—	—	—
24 Cr		**X**	B	**A**	C	C	42 Mo		**X**	O	O	B	**A**	74 W	C	O	B	O	O	O	92 U	O	O	O	O	O
25 Mn		**X**	**A**	B	A	B	43 —		—	—	—	—	—	75 Re		O	O	O	O	O						
26 Fe		B	B	**A**	B	**A**	44 Ru		**X**	O	O	O	O	76 Os		O	O	O	O	O	*Rare Earths*					
27 Co	C	C	B	O	O	B	45 Rh		**X**	O	O	O	O	77 Ir		O	O	O	O	O	58 Ce	**L**	**X**	B	B	O
28 Ni	C	C	C	O	O	O	46 Pd		C	C	O	O	O	78 Pt		C	**A**	O	O	O	59 Pr	**L**	**X**	O	O	O
29 Cu	B	C	**A**	C	O	O	47 Ag	B	**A**	C	C	O	O	79 Au	B	C	C	O	O	O	60 Nd	**L**	**X**	O	O	O
30 Zn	B	C	C	B	B	O	48 Cd	B	O	C	B	B	O	80 Hg	B	B	B	B	B	O	61 —	—	—	—	—	—
																					62 Sa	**L**	**X**	O	O	O
31 Ga	C	**L**	C	C	C	O	49 In		**L**	**A**	C	C	O	81 Tl	B	**L**	C	C	C	O	63 Eu	**L**	**X**	O	O	O
32 Ge		C	C	C	C	B	50 Sn		**A**	**A**	C	C	C	82 Pb		C	B	B	B	B	64 Gd	**L**	**X**	O	O	O
33 As		C	C	B	B	C	51 Sb		C	B	B	B	B	83 Bi		C	B	B	B	B	65 Tb	**L**	**X**	O	O	O
34 Se		**A**	**A**	B	B	B	52 Te	B	C	O	B	B	B	84 Po		—	—	—	—	—	66 Dy	**L**	**X**	O	O	O
35 Br		C	C	B	B	B	53 I	B	C	B	B	O	O	85 —		—	—	—	—	—	67 Ho	**L**	**X**	O	O	O
36 Kr		**A**	**A**	**A**	B	O	54 Xe		**A**	B	**A**	C	O	86 Rn		O	O	O	O	O	68 Er	**L**	**X**	O	O	O
																					69 Tu	**L**	**X**	O	O	O
37 Rb		**L**	C	B	O	O	55 Cs		**L**	C	C	O	O	87 —		—	—	—	—	—	70 Yb	**L**	**X**	O	O	O
38 Sr		**L**	**A**	O	B	O	56 Ba		**L**	**A**	O	C	O	88 Ra		**L**	C	O	O	O	71 Lu	**L**	**X**	O	O	O

Table II. *Statistics of wave-length data shorter than λ2000.*

	I	II	III	IV	V
A	14	20	16	10	5
B	4	17	24	27	25
C	20	18	11	10	5
L	26	0	0	0	0
X	10	15	0	0	0
O	11	14	32	35	46
A+X+L	50	35	16	10	5
B+C+O	35	49	67	72	76
%A+X+L	59	42	19	12	6

These ratings apply only to the observations in the vacuum ultraviolet and have no direct reference to the degree of completeness of the analysis of the spectrum. That question is considerably beyond the scope of the present article and has been treated by Russell (1935) and more recently by Shenstone (1939).

For the first five spectra (I, II, III, IV, V and for the unassigned lines u) of each element, these symbols have been gathered together into Table I. The table has been divided into two parts to emphasize the contrast between the relatively complete knowledge about the spectra of atoms of atomic number up to 20 (calcium) and the relative ignorance about the spectra of atoms of higher atomic number. It is natural that the simpler spectra should have been investigated first and most thoroughly. It will be remembered that with atomic number 21 (scandium) the *d* electron introduces more complexity into atomic spectra. Many positions in Table I would be blank because no observations at all have been made of that spectrum at wave-lengths shorter than λ2000. One of three other symbols (**L, X, O**) has been entered to represent the probable state of such spectra. **L** denotes spectra in which it is known or believed that no ordinary emission lines lie at wave-lengths shorter than λ2000. **X** denotes spectra in which it is known or believed that no *important* lines lie in this spectral region, that is, no lines giving information about terms not otherwise accessible. It should be pointed out that such spectra may contain lines of wave-lengths shorter than λ2000 which may be useful as standards of wave-length, in that such wave-lengths may be calculable by the combination principle as explained in an earlier section. O denotes spectra having no observations, but the expectation of important lines at wave-lengths less than λ2000. Since **A, L,** and **X** represent spectra least in need of further observation in emission in the vacuum ultraviolet they have been printed with bold-face type in Table I. The symbols **B, C,** and **O** appear sufficiently often to indicate that much remains to be done. Some statistics gathered from Table I may be of interest and appear as Table II.

An examination of diagonal lines (from upper left to lower right) of Table I shows isoelectronic sequences among the first five spectra (the neutral atom and the first four stages of ionization) for which data are available. More extended isoelectronic sequences are listed in Table III, where missing members of the sequence are enclosed in parenthesis. The extent of the information available about each member of such longer sequences can be found by looking up the appropriate spectra in Appendix C.

So far we have discussed emission spectra only. Absorption spectra have been investigated for

Table III. *Long isoelectronic sequences.*

No. of Electrons	Sequence	Missing Members
1	H I–C VI	
2	He I–C V	
3	Li I–Na IX	(Ne VIII)
4	Be I–Al X	(Ne VII)
5	B I–Al IX	(Ne VI)
6	C I–Al VIII	
7	N I–Cl XI	(P IX, S X)
8	O I–Cl X	(P VIII, S IX)
9	F I–Ca XII	(P VII, A X)
10	Ne I–Co XVIII	(P VI, S VII, A IX)
11	Na I–Cu XIX	
12	Mg I–Co XVI	
13	Al I–Co XV	
14	Si I–Sc VIII	
15	P I–V IX	
16	S I–Fe XI	
17	Cl I–Co XI	
18	A I–Fe IX	
19	K I–Fe VIII	
20	Ca I–Ni IX	
21	Sc I–Fe VI	
22	Ti I–Ni VII	
23	V I–Cu VII	
28	Ni I–Br VIII	
29	Cu I–Br VII	
30	Zn I–Br VI	
35	Br I–Zn VI	
37	Rb I–Mo VI	
46	Pd I–I VIII	
47	Ag I–Te VI	
78	Pt I–Bi VI	

only *16* elements: Mg, Si, A, K, Mn, Zn, Kr, Rb, Ag, Cd, I, Xe, Cs, Hg, Tl, Pb, and papers relative to each of these have been listed under that element in Appendix C. The work of Beutler (1933) deserves special discussion and has already been mentioned as dealing with spectra which may be considered as the transition between optical spectra and x-rays. Perhaps the best approach to this work is to follow Beutler's first paper and to discuss the essential contrast between absorption processes in optical spectra and those in x-ray spectra. In the former the most loosely bound electron is shifted to an unoccupied "orbit" (subject to the usual restrictions governing changes in angular momentum and spin) or is removed entirely from the atom (still subject to these same restrictions). These processes give rise to a series of lines and, following them at shorter wave-lengths, a band of continuous absorption. In the case of x-ray absorption, the energy necessary to remove an inner electron to any of the vacant "orbits" is very nearly the same as that necessary to eject it completely from the atom. In the K absorption of argon, for example, the difference was found by Coster and van der Tuuk (1926) to be 1.7 electron volts in a total energy change of about 10,000 electron volts. A slight structure, not fully resolved, in the long wave-length edge of the K x-ray absorption band of argon corresponds to the optical line absorption scattered through some 200A.

If the information about vacant orbits in the neutral atom could be obtained in full from the optical absorption spectra, these other processes would be of only passing interest. But because of differences in screening and in coupling, the energies (and sometimes the term structure) of the atom are different when a normally vacant "orbit" is temporarily filled in these two ways. The detection of structure in the absorption band in the ordinary x-ray region taxes the available resolving power, but comparable information should be available, in the vacuum ultraviolet region, from absorption spectra associated with the excitation of intermediate electron shells. There one would expect the energy differences to be sufficient, compared with the total energy, to separate the line absorption clearly from its associated continuous absorption. In a series of papers with his collaborators (listed by element in Appendix C), Beutler observed just such absorption spectra for the following seven elements: K, Zn, Rb, Cd, Cs, Hg, Tl. Most of these were located in the λ1200–λ600 region and all arose from the excitation of an electron from the least firmly bound *completed* shell of electrons, for example from a 4d electron in Cd and a 5p electron in Cs. While these are perhaps technically x-rays in excitation they exhibit clearly all of the multiplets and series relations of a line spectrum. For this reason one is justified in speaking of such spectra as providing the transition between optical and x-ray spectra.

These new absorption spectra display all of the multiplicities and term arrangements to be expected from the Hund theory. The term values bear a certain relation to those of the arc spectrum of the element of next higher atomic number, but with different multiplicities. Examples are found of (L,S), (j,j) and intermediate coupling. As these are clearly spectra of the neutral atom, Beutler proposes to designate them as I^b spectra, tacitly reserving I^a to designate the more familiar spectrum of the neutral atom. Similar superscripts can be added to higher Roman numerals, if one wishes to designate as separate spectra the few known examples of the excitation of inner electrons in spark spectra. In thallium the I^b spectrum due to excitation of a 6s electron was observed in the λ2500–λ1400 range and also the I^c spectrum, from the excitation of a 5d electron, which came in the λ900–λ600 range. The I^a system of terms converges to the ground state of the II spectrum of the same atom while (in the alkali metals) the I^b system of terms converges to the p^5s excited state in the II spectrum. If one were to extend the notation, the K x-ray absorption in argon would be denoted as I^e.

Most of the terms in I^b spectra lie above the ionization limit in the corresponding I^a spectrum. Such terms (and the corresponding absorption lines) are considerably broadened by auto-ionization, whenever, as was predicted by Shenstone (1931), there exists beyond the I^a limit a continuum having the same value of L, S, J and the same parity. The broadening seems to be proportional to the intensity of the perturbing continuum at the same wave-length and presumably has prevented observation of I^b spectra in emission. Shenstone's rules for auto-ionization clearly fit except in a few doubtful cases with intermediate coupling. The same interaction between the wave functions of the I^b terms and the associated I^a continua, which causes this broadening, increases the intensity of those I^b absorption lines by a power of ten. It seems probable that these intense absorption processes control the form of the dispersion curve in such elements. In fact, this was shown by Beutler (1935) to be the case for the rare gases argon, krypton, and xenon. Here the anomalously strong absorption lines (also broadened) are not those of the I^b spectrum. The ordinary (I^a) spectrum in these rare gases consists of separate groups of lines converging to each of the two limits, the ${}^2P_{1\frac{1}{2}}{}^0$ and ${}^2P_{\frac{1}{2}}{}^0$ states of the ion. Those lines converging on the ${}^2P_{\frac{1}{2}}{}^0$ limit which lie above the ${}^2P_{1\frac{1}{2}}{}^0$ limit are broadened. They are very much stronger in absorption than either the unbroadened lines of either group below the ${}^2P_{1\frac{1}{2}}{}^0$ limit or the continuum beyond either limit. The dispersion curves for these rare gases are found to predict principal absorption at just the wave-lengths of the strengthened and broadened lines.

X. Molecular Spectra

OBSERVATIONS in the vacuum ultraviolet, both in emission and in absorption, have supplied important data in molecular spectra. No attempt will be made to list publications of such data. Sponer (1935) tabulated the data of molecular spectra then available. Relatively few papers on the spectra of diatomic molecules have appeared since that time. Many more investigations have been made of the spectra of polyatomic molecules. A paper by Sponer and Teller, now in preparation for these Reviews, will summarize the available data of the spectra of polyatomic molecules in all wave-length ranges.

The tables of Sponer (1935) show that the spectra of the following diatomic molecules or molecular ions had been investigated in the vacuum ultraviolet up to that time: H_2, N_2^+, N_2, O_2, S_2, I_2, BrCl, ICl, IBr, CO, NO. Most of these molecules have relatively high heats of dissociation. Whether or not the spectrum of a molecule (or of a molecular ion) extends into the region of the vacuum ultraviolet, depends largely on the distribution in energy of the possible electronic states of the molecule. Where the electronic structure of the molecule in its unexcited state forms a "closed shell," the excitation energy of its first excited state will be relatively high, and transitions from it to the unexcited state will give bands in the vacuum ultraviolet. This is analogous to the situation with the atomic spectra of the inert gases. H_2, N_2 and CO have such "closed shells" of electrons.

It is unfortunate that the shift of interest from vibrational to rotational structure in molecular spectra has prevented the remeasurement, under modern accuracy, of some of the vibrational systems first studied. Even the bands of O_2 and N_2 listed in Appendix A could profitably be remeasured.

Observations on molecular spectra require relatively small resolving power if they are restricted to vibrational systems in emission or absorption, or to absorption continua. The rotational structure of the bands of diatomic molecules requires resolving power of the order of 30,000. With a practical resolving power of 300,000, Liebermann (1940) was able to resolve the rotational structure of some bands of CS_2 at $\lambda 3200$. It will not be easy to obtain this resolving power at shorter wave-lengths. The prospect is not encouraging for the resolution of the rotational structure in the bands of still more complicated polyatomic molecules.

The bands in the Schumann region of N_2 and CO (the latter most easily excited by an electrical discharge in CO_2) are convenient light sources for use in the final optical adjustment of a spectrograph since they give groups of many closely spaced lines of comparable intensity.

A few remarks may be in order about bands that sometimes appear in the course of other investigations. N_2, O_2 and NO bands may appear in the spectra of electrical discharges in other gases if there is a very small air leak into the gas supply. If the leak is large the spectrum will be blacked out over considerable portions of the vacuum ultraviolet. CO bands may appear in gas discharge spectra if the electrodes have not had adequate outgassing. This is particularly true for electrodes of iron or nickel. More troublesome are the band spectra which look like line spectra. Because of the very low moment of inertia of the hydrogen molecule, there is wide spacing between the lines of the rotational structure of its spectrum. The characteristic band structure is not apparent and the spectrum has been called the "many lined" spectrum of hydrogen (see Richardson, 1934). There is a single band in helium in the vicinity of λ600, first identified by Sommer (1927) and later studied by Nickerson (1935). (Certain features of its origin are still unexplained.) Under certain conditions of excitation close doublets appear in nitrogen in the vicinity of λ1000. These have been identified by Birge and Hopfield (1928) as a partial development of the ordinary band spectrum of nitrogen in that region.

For completeness one should mention that in atomic spectra there are often lines which appear as unresolved bands. These are lines arising from terms above the ordinary ionization limit in the atom and are broadened by auto-ionization.

XI. Spectra of the Solid State

SKINNER (1939, 1940) has discussed in some detail the soft x-ray spectroscopy of the solid state. The subject is very similar in its techniques to our general subject and sufficiently related in theory, so it deserves some brief mention. According to the modern picture, the valence electrons in a solid move about in the lattice of the crystal with energies distributed through a discrete band. No more than two electrons (one each for the two possible spin orientations) can have identical energies. All energy levels within that band are filled at absolute zero, but, in a conducting solid at temperatures above the absolute zero, some of the electrons will have higher energy in the permitted, but unfilled, zone of energies lying immediately above the filled zone. This diffusion of electrons into the unfilled region on the energy diagram is, of course, a function of the temperature. In a nonconducting solid, however, there is a forbidden zone of energy values between the filled and unfilled zones. An electron can reach the unfilled zone only by absorption of sufficient energy to carry it across the forbidden zone. A crystal is transparent in the wave-length range corresponding to quantum energies insufficient to bridge the forbidden zone, but opaque to shorter wave-lengths. The related phenomenon of photo-conductivity (Pohl, 1938) is included by Manning and Bell (1940) in a recent discussion in these Reviews of certain phenomena in solid dielectrics.

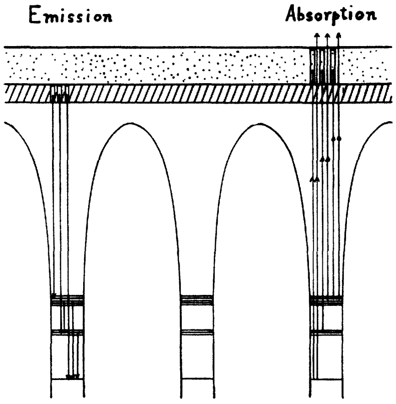

FIG. 5. Electron energy bands in conductors. (Diagonal shading denotes energy band normally filled and dots energy band normally empty.)

Figures 5 and 6 are (schematic) illustrations of this essential difference between conductors and nonconductors and illustrate the spectroscopic possibilities for obtaining information about these energy bands, both filled and unfilled. Transitions from filled to unfilled bands give rise to the opacity of conductors and to the absorption, below a characteristic wave-length limit, in nonconductors. The visible emission spectra of solids, arising from the return of electrons from the unfilled band to temporarily vacant places in the filled band has been observed by Mohler and Boeckner (1931). But transitions between two broad bands of energy give broad continuous spectra difficult of interpretation. More useful are the emission spectra corresponding to transitions from the filled band of energies to temporary vacancies in the outermost shell of electrons associated with individual atoms of the lattice, and the absorption spectra corresponding to ejections of electrons from these atomic shells to the unfilled band of energies. Some data might be obtained from spectra associated with transitions between these bands and the inner shells of atomic electrons. But, as was the case in the comparison of Beutler's atomic absorption spectra with the x-ray absorption spectra of gases, the energy spread of the bands, compared with the total energy of the harder x-rays, taxes the available resolving power. The difficulty about

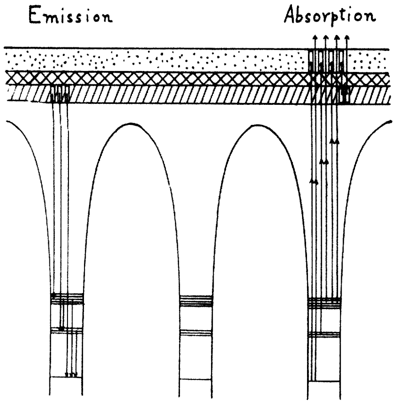

FIG. 6. Electron energy bands in nonconductors. (Diagonal shading denotes energy band normally filled, cross-hatching forbidden band and dots energy band normally empty.)

resolving power is a double one, both because of instrumental limitations and because of the broadening due to radiation damping. Assuming a hydrogen-like atom, Skinner points out that this radiation broadening amounts to 4×10^{-4} volts at λ100, 4×10^{-2} volts at λ10 and 4 volts at λ1.

Skinner gives an extensive bibliography of observed emission and absorption spectra of solids in the soft x-ray region and presents, from the data of a number of observers, experimental curves showing the density of energy levels in filled and unfilled bands in lithium, magnesium and aluminum. In all cases of metals for which the necessary data are available, the short wave-length edge of the emission band coincides with the long wave-length edge of the absorption bands. This is to be expected if the filled and unfilled energy bands are adjacent to one another.

In observations with a target at 110°K, 300°K and 680°K, Skinner was able to show a broadening of the emission bands in aluminum, due to the thermal change in the energy distrubution of its electrons.

Observations on soft x-ray spectra from solids are still largely confined to elements of low atomic number, but further investigations should fill this deficiency. Results on a few alloys and a few compounds also suggest very promising fields for further work. It is now clear why the early investigations of soft x-rays from metals by the method of critical potentials (Kurth, 1921, Richardson and Chalklin, 1926, K. T. Compton and Thomas, 1926, and others) gave results somewhat difficult to interpret. Aside from the experimental difficulties of surface contamination, the spread in the energy values of the valence electron was not realized. When the emission spectrum of soft x-rays was first observed, the breadth of the lines was surprising (Thibaud, 1927 and Söderman, 1929).

If one experimental handicap could be removed, absorption measurements in this region would be greatly facilitated. The region of greatest interest, λ300−λ100, is too short in wave-length for the gas discharge source of continuous spectrum to be used and too long in wave-length to obtain, in sufficient intensity, the x-ray continuous spectrum. It has, therefore, been necessary to use the many lines of the spectrum of a hot spark as the background for absorption measurements. This has introduced some complications in the photographic photometry and also has limited the resolving power.

XII. ASTROPHYSICAL AND OTHER APPLICATIONS

DATA obtained in the course of laboratory investigations of atomic spectra in the vacuum ultraviolet have been of paramount importance in the interpretation of the spectra of the galactic (gaseous) nebulae. Some of these objects shine by the light scattered from adjacent stars while others have an emission spectrum of their own. These latter nebulae are always associated with very hot stars of spectral type earlier than B 1 (Hubble, 1922). Menzel (1926) and Zanstra (1927) suggested independently that absorption of very short wave-length ultraviolet radiation, coming from the hotter stars, led to the excitation of the emission spectrum. From the strength of the Balmer lines of hydrogen in emission it has been possible to estimate the total intensity of the ultraviolet continuum of the star beyond the limit at λ912 of the Lyman series of hydrogen. Comparison of this with the intensity of the continuous spectrum in observable regions gives a "blackbody" surface temperature for the exciting star. Values were obtained as high as 100,000°K. The nebulae contain a considerable density of hydrogen resonance radiation (λ1215) for which they are highly absorbing. The nebulae are very transparent at longer wave-lengths.

Certain lines in the nebular spectra, including the strongest lines, were shown by Bowen (1928) to arise from "forbidden" transitions in N II, O II and O III. These transitions start from metastable states in these ions, to which they had been excited by collisions with photoelectrons produced in the nebula by the portion of the primary stellar radiation of wave-length shorter than λ912. A negligible number of these photoelectrons will have sufficient energy to excite the ordinary lines of the spectra of these elements. Recombination of ions and electrons is most infrequent. The transitions from the metastable states have very low probabilities, of the order of 1 sec.^{-1} or even less (Condon, 1934). Under laboratory conditions it is impossible to get free times between collisions much over a thousandth of a second, yet in nebulae these free times are estimated to range from hours to weeks. Subsequent investigations by Bowen and others have led to identification of a considerable number of forbidden lines in nebular spectra, including, in addition to those first discovered, lines of N I and O I and of fluorine, neon, magnesium, sulphur, chlorine, argon, calcium and iron and possibly silicon and potassium. Pertinent data have been summarized by Bowen (1935), by Boyce (1936) and by Bowen and Wyse (1939). The physical aspects of forbidden lines have been discussed in these Reviews by Bowen (1936). It appears that about two-thirds of all the lines listed by Bowen and Wyse are definitely identified, but the remaining third are all among the very faint lines. Forbidden lines of Fe II were discovered by Merrill (1928) in the spectrum of η Carinae, and have been found in the spectra of some novae. Identifications in the spectra of novae are made difficult by very broad lines, but sometimes significant successive changes occur in the spectrum as the nova runs its course.

Not only does knowledge of spectra in the vacuum ultraviolet lead to an understanding of the excitation mechanism in nebulae, but it also provides the data for computing the position of the forbidden lines. Reference to Fig. 7, a skeletonized Grotrian diagram of O I, will illustrate this point. Forbidden lines of the lighter elements may be divided into two principal types, nebular and auroral. (For neutral oxygen both types of these transitions occur in both nebulae and the aurora. The type of transition is named for the place where that line in oxygen is the stronger.) The *wave number* of the auroral line of O I is equal to the difference between the wave numbers of two vacuum ultraviolet lines at λ1217 and λ999. The *difference of wave number* of the two nebular lines of O I is equal to the difference between the wave numbers of the two vacuum ultraviolet lines at λ1304 and λ1302. The absolute wave number of the nebular type lines can be calculated only if intersystem combination lines can be found somewhere else in the spectrum to provide the connection between the triplet and singlet systems of terms. In several cases these intersystem combination lines have confirmed a previous tentative identification of nebular lines, but they have not yet been discovered in O I. In the absence of intersystem combination lines, estimates about the absolute wave numbers of the nebular type lines can be made in several ways: interpolation or extrapolation along an isoelectronic sequence, or from well-defined series in both systems converging to the same limit, or (with ions) from well-defined series in the next lower stage of ionization converging on both the normal and metastable states of the ion. This latter approach is obviously impossible for a neutral atom. The auroral line in neutral oxygen was produced in the laboratory by McLennan and Shrum (1925) and studied

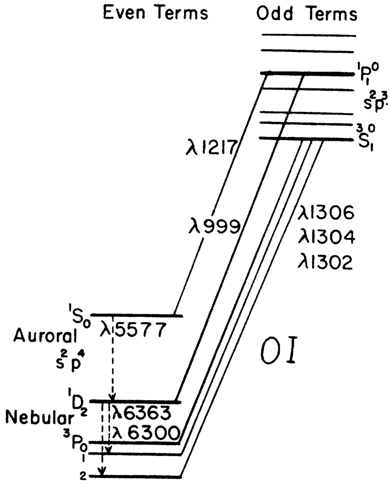

FIG. 7. Partial Grotrian diagram of neutral oxygen atom to illustrate relation of forbidden lines to lines in the vacuum ultraviolet.

further by McLennan, McLeod and McQuarrie (1927). The nebular lines in neutral oxygen were produced in the laboratory by Hopfield (1931). In these experiments the mere weight of numbers in a high concentration of metastable atoms was used to offset the low probability of the emission of the lines. The method would be very much harder to apply to ionized atoms.

In still another way data from the vacuum ultraviolet have been of use in the interpretation of nebular spectra. Among the few "permitted" lines, other than those of hydrogen and helium, present in the nebular spectra are certain partial multiplets of O III and N III. In the case of the oxygen lines, these all arose from a single high odd level, or from even levels reached by radiating transitions from this high odd level. Other (laboratory) members of the multiplet were missing. Bowen (1935) showed that this one high odd level was selectively excited by absorption of the He II resonance radiation at $\lambda 303$. Further, by another coincidence of wavelengths, the O III line at $\lambda 374$, which follows the emission of certain pairs of lines in the partial multiplets, itself leads to selective excitation of one level in N III and the subsequent emission of partial multiplets in that spectrum.

These various ultraviolet mechanisms evidently may play important parts in novae and in Wolf-Rayet stars, in fact in all stars with bright-line spectra. Even the sun appears to emit a far greater quantity of ultraviolet radiation than would a blackbody at its effective surface temperature. It is not yet clear what fraction of the excess ultraviolet comes from "hot spots" on the solar surface rather than from the surface as a whole. Evidence for this excess ultraviolet comes from a number of phenomena, some of which will be mentioned briefly. Ozone production in the atmosphere depends largely on absorption of radiation in the Schumann region. A considerable fraction, at least, of the ionization in the ionosphere is produced by solar ultraviolet light. Certain types of rapid ionospheric changes seem to be caused by added bursts of light from active areas on the surface of the sun. Regions of ionization at various heights in the atmosphere are probably due to various processes by which constituents of the atmosphere become ionized. The absorption coefficient for each of these processes will determine the depth below the top of the atmosphere at which it is most effective. It is clear that all or nearly all of these processes are due to radiations in the vacuum ultraviolet part of the spectrum, but the exact correlation between the individual processes and the regions of the ionosphere is not yet entirely determined. The subject has been discussed by Chapman and Price (1937), Wulf and Deming (1938), Preston (1940) and others.

The evidence in connection with the "dawn flash" is considerably more striking and has been discussed by Saha (1937). Observations of Slipher (1933) have shown that the "negative" bands of nitrogen (due to N_2^+), very faintly present in the night sky, flash out strongly when the rays of the returning sun first touch the top of the atmosphere. The bands arise from the so-called *A* excited state of the ionized nitrogen molecule. Hopfield (1930) could find no trace of an absorption continuum corresponding to the formation of the ionized nitrogen molecule in its normal state, but only the continuum, beginning at $\lambda 660$ leading to the formation of N_2^+ in its excited (*A*) state. Objection might be made that the function of the sunlight is simply to excite the N_2^+ ions already present in the upper atmosphere. But it is difficult to see how the molecular ions would escape recombination during the night (a flash of the negative bands of nitrogen, comparable in intensity, ceases abruptly when the last rays of the setting sun leave the top of the atmosphere). Since it seems impossible to find any ionizing agent, other than sunlight, to maintain the supply of nitrogen molecular ions, and since, when these ions are formed by absorption of light, they are already prepared to radiate the negative bands, Saha's argument seems very convincing.

Further evidence of excess solar ultraviolet has been pointed out by Saha in connection with bands of CO^+ and N_2^+ in the spectra of comets. However, because the low density of the comets is unfavorable for recombination, the argument is admittedly less certain. Excitation in the solar chromosphere also strongly suggests an excess of ultraviolet radiation (Cillié and Menzel, 1935). Hemmendinger (1939) has pointed out selective effects in the chromosphere which are most easily explained by the presence of strong radiation in the Lyman series of hydrogen (λ1215, λ1025, λ972, etc.). A strong parallel between intensities in the lines of the solar corona (over different positions on the limb of the eclipsed sun) and intensities of helium lines in the underlying portions of the chromosphere suggests a common source of excitation energy.

The spectrum of the solar corona is the outstanding unsolved problem of astronomical spectroscopy, despite many attempts to identify the elements giving rise to these lines. An interesting suggestion by Paschen, reported by Beutler (1933), is that these lines (observed in the λ10,000–λ3000 region) may be emitted following the excitation of inner electrons by ultraviolet light of very short wave-length. Whatever the element or elements giving rise to these mysterious lines, the excitation must be such that none of the familiar lines can disclose their identity.

The larger energies possessed by quanta of radiation in the vacuum ultraviolet make possible photochemical processes for which radiation of longer wave-length is impotent. The correlation between spectroscopy and photochemistry has already been discussed by Noyes (1933) in these Reviews. A number of investigators have used radiations in the Schumann region. Intensities available from monochromators[7] are rather low. The xenon lamp of Harteck and Oppenheimer (1932), further developed by Groth (1936, 1937), has widened the possibilities of investigation. The lamp gives strong radiation in the two resonance lines of xenon, λ1470 and λ1295, both of which penetrate fluorite windows. A convenient filter cell, which may contain oxygen or which may be evacuated, permits observations with λ1295 alone or with both lines. A series of papers by Harteck, Groth and others from the Hamburg laboratory have described photochemical studies made with this lamp. A summary of results was published by Groth (1939). The photochemical production of ozone, already known, from the work of Kistiakowsky and Smith (1935), to have a photochemical yield of 2 molecules of ozone per absorbed quantum, was used as a quantitative device to measure intensities. The ozone produced was measured chemically by the iodine it liberated from a solution of potassium iodide, or physically by its absorption (in another cell, a long tube with quartz windows) of mercury radiation at λ2537. Among a considerable number of reactions studied was the production of formaldehyde from a mixture of carbon monoxide and hydrogen (Faltings, Harteck and Groth, 1938).

Other relatively monochromatic light sources should be possible despite the easy discoloration of lithium fluoride (Schneider, 1937). Groth (1939) reports unpublished experiments by Groth and Harteck with a krypton lamp to give λ1236 and λ1165. A hydrogen lamp for λ1215 might best operate on a mixture of hydrogen with helium or neon.

As already mentioned, photoelectric cells have been used for the detection of vacuum ultraviolet radiations. It is possible that an investigation of the photoelectric effect in this spectral region would be interesting with metals having high work functions (under clean surface conditions). P. E. Sabine (1917) carried the test of Einstein's photoelectric equation into the Schumann region. The vacuum ultraviolet radiations from electrical discharges in gases (Thomson, 1925) probably play a part photoelectrically in supplying electrons from the cathode in a cold-cathode discharge.

Lyman (1928, pp. 123, 124) has discussed the bactericidal and abiotic action of radiation in the Schumann region. Blank and Arnold (1935) described experiments on *bacillus subtilis* in which they took advantage of the "window" in air between λ1300 and λ1100. In the presence of living material, any radiation in this region must of course run the gauntlet of the absorption bands of water vapor (Rathenau, 1933). Recent measurements by Preston (1940) show that λ1215 is strongly absorbed by water vapor. The penetration into living material would be less deep than with ordinary ultraviolet light or with x-rays. From some points of view this might be an advantage as it would be known exactly where the energy was received.

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[7] A fluorite double monochromator, described by Hilsch and Pohl (1930), has been used in measurements of the transparency of crystals.

laboratory in the spectroscopy of the vacuum ultraviolet. The writer is indebted to his colleague Professor E. S. Lamar for helpful discussions on the electrical characteristics of spectroscopic light sources. The bibliography of atomic spectra in the vacuum ultraviolet (Appendix C) would have been impossible without the meticulous assistance of Dr. Lore Misch, which is most gratefully acknowledged. Thanks are due to a considerable number of spectroscopists, in this laboratory and elsewhere, for advice on various points. It is regretted that world conditions have prevented sending the manuscript to Docent Edlén for his promised criticisms and suggestions.

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R. Tousey, J. Opt. Soc. Am. **29**. 235.

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APPENDIX A. PRINCIPAL ABSORPTION BAND-HEADS IN OXYGEN AND NITROGEN

Oxygen.—Schumann-Runge System

Bands from lowest vibrational state, S. W. Leifson, Astrophys. J. **63**, 73 (1926).

λ	λ	λ	λ
(1971.4)	1883.0	1816.8	1775.9
1946.8	1864.2	1804.3	1769.2
1924.8	1846.9	1793.4	1763.8
1903.1	1831.1	1783.9	1759.6
			1757.7

Additional bands, from the next to the lowest vibrational state, have been observed by Ducleaux and Jeantet (Comptes rendus **173**, 581 (1921)) in somewhat longer optical paths.

λ 1960.1 1938.6 1918.9 1900.7.

The rotational structure of some of these bands has been studied by a number of investigators including Ossenbruggen (Zeits. f. Physik **49**, 167 (1928)) and Curry and Herzberg (Ann. d. Physik **19**, 800 (1934)). The bands in this system degrade toward longer wave-lengths.

Nitrogen

Birge and Hopfield, Astrophys. J. **68**, 257 (1928).

λ	λ	λ
1450.09	1353.61	1249.25
1415.88	1325.16	1226.63
1383.76	1298.37	1205.27
	1273.13	

Watson and Koontz (Phys. Rev. **46**, 32 (1934)) have measured the rotational structure of some of the bands of this system. The bands in this system degrade toward longer wave-lengths.

Appendix B. Wave-Length Standards in the Vacuum Ultraviolet

Table I. *Wave-length standards in copper* (*Shenstone, 1936*).

λ (calc.)	*I*	P.E. in 0.001A	λ (calc.)	*I*	P.E. in 0.001A	λ (calc.)	*I*	P.E. in 0.001A	λ (calc.)	*I*	P.E. in 0.001A
2000.339	60	4	1517.630	20	2	1275.570	30	2	1031.764	8	1
1989.849	30	4	1496.686	35	4	1274.463	3	2	1028.326	25	1
1979.947	50	4	1473.976	25	2	1274.069	3	2	1027.830	50	1
1970.489	15	4	1444.131	2	2	1266.308	10	1	1022.100	5	1
1944.586	25	4	1442.136	15	2	1265.504	15	1	1019.652	15	1
1663.003	30	3	1402.776	15	2	1250.045	10	2	1018.705	50	1
1660.005	20	3	1399.355	3	2	1248.790	5	2	1012.595	25	1
1656.326	20	3	1393.126	10	2	1241.961	2	1	1011.433	2	1
1649.457	25	3	1371.840	20	2	1219.332	1	2	1008.568	30	1
1621.426	60	3	1370.558	2	2	1214.553	1	2	1004.053	30	1
1617.914	20	3	1363.501	5	2	1185.899	2	2	1001.010	8	1
1610.298	15	3	1362.598	20	2	1109.742	1	2	992.951	25	1
1608.638	25	3	1359.935	5	2	1106.446	3	2	912.022	0	2
1606.834	40	3	1359.010	20	2	1088.393	20	2	911.654	1	2
1604.848	20	3	1355.304	15	2	1069.193	50	2	884.824	5	2
1602.387	40	3	1351.837	25	2	1066.133	20	2	883.837	5	2
1598.402	40	3	1350.592	15	2	1065.781	20	1	876.719	20	2
1593.557	60	3	1326.394	10	2	1059.094	60	1	866.440	5	2
1590.164	40	3	1325.511	3	2	1058.796	40	2	826.995	30	2
1569.216	10	2	1314.335	30	2	1055.795	40	2	813.882	20	2
1566.411	40	2	1314.147	15	2	1054.690	60	1	810.997	15	2
1565.925	40	2	1309.463	15	2	1049.754	50	1	736.031	25	2
1558.344	30	2	1308.296	30	2	1049.363	20	2	735.519	20	2
1541.701	75	2	1299.267	10	2	1044.742	80	1	724.487	15	2
1540.391	30	2	1298.394	15	2	1039.345	60	2	685.396	2	2
1535.004	25	2	1297.549	2	2	1036.468	60	1	685.139	8	2
1519.491	50	2	1281.458	8	4	1035.160	8	1			

Table II. *Wave-length standards in iron* (*Green, 1939*).

	Intensities			Intensities	
λ (calc.)	Helium Schüler Tube	Spark	λ (calc.)	Helium Schüler Tube	Spark
2001.025	30	30	1670.990	1	—
1904.785	15	5	1663.220	15	2
1903.384	1	—	1659.479	20	10
1898.535	10	2	1658.771	15	2
1859.744	15	10	1654.476	5	1
1851.526	1	—	1652.482	0	—
1848.771	12	2	1643.576	15	2
1842.238	0	—	1640.150	12	2
1833.073	0	—	1637.398	15	2
1826.994	1	1	1633.906	15	2
1818.516	2	1	1632.665	1	—
1815.411	0	1	1625.520	20	8
1726.391	12	8	1623.090	8	1
1724.962	8	1	1612.805	20	8
1720.611	20	20	1584.949	15	1
1718.100	2	—	1577.167	1	—
1712.998	20	25	1574.921	20	1
1709.551	0	—	1574.769	0	—
1702.044	25	25	1573.826	5	—
1699.195	2	—	1572.754	1	—
1696.794	8	—	1570.244	20	1
1693.935	0	—	1569.674	12	—
1693.475	0	—	1568.017	8	—
1691.272	8	1	1566.821	20	1
1686.454	8	1	1563.788	25	2
1685.952	5	1	1559.084	20	2
1676.854	1	—	1550.273	1	—
1674.254	2	1			

Table III. *Wave-length standards in hydrogen and helium* (*Paschen, 1929*).

Hydrogen (calc.)	Helium (He II) (calc.)	
1215.664	1640.409	303.7788
1025.717	1215.129	256.3145
972.532	1084.940	243.0244
949.739	1025.270	237.3297
937.799	992.361	234.3452
930.745	972.109	
926.222	958.696	
923.148	949.326	

Table IV. *Wave-length standards in carbon, nitrogen and oxygen* (*More and Rieke, 1936*).

Spectrum	λ	*I*	Spectrum	λ	*I*
C I	1658.135	8*d*	N I	1200.707	5
C I	1657.908	8*d*	N I	1200.218	6
C I	1657.388	5*d*	N I	1199.550	7
C I	1656.994	15*d*	N I	1176.502	1
C I	1656.271	8*d*	N I	1134.979	4
C I	1560.702	15*d*	N I	1134.417	3
C I	1560.313	8*d*	N I	1134.168	3
N I	1494.670	4	N II	1084.582	3
C II	1335.703	18*d*	N II	1083.996	2
C II	1334.534	15*d*	O I	999.493	2
C I	1329.099	5	O I	990.794	3
C I	1328.820	3	O I	990.205	4*d*
O I	1306.023	6	O II	834.467	2
O I	1304.858	8	O II	833.332	1
O I	1302.174	8	O II	832.764	0
O I	1217.643	2			

Appendix C. Bibliography of Atomic Spectra in the Vacuum Ultraviolet

(Prepared with the collaboration of Dr. Lore Misch)

The two papers most frequently quoted appeared in a Swedish journal with a rather elaborate Latin title. As they are each rather long papers they will be quoted simply as Edlén, Monograph and Söderquist, Monograph. The full reference to each is given below. Both are written in German.

Edlén, Reg. Soc. Sci. Upsaliensis Nova Acta, Series IV, Vol. **9**, No. 6 (1934).
Söderquist, Reg. Soc. Sci. Upsaliensis Nova Acta, Series IV, Vol. **9**, No. 7 (1934).

Observed wave-length data have been evaluated as follows:

A—Accuracy sufficient, number of lines sufficient for analysis of particular spectrum.
B—Accuracy sufficient, number of lines insufficient for analysis of particular spectrum.
C—Accuracy insufficient.

A, B, C symbols apply only to measurements and *not* to analyses.

If no observations have been made on a particular spectrum below λ2000, then one of the following symbols is used:

L—Series limit above λ2000. No ordinary lines expected below λ2000.
X—Series limit below λ2000, but all terms may be located by lines above λ2000. No observations yet made below λ2000.
O—Series limit below λ2000. No observations yet made below λ2000.

Values of the ionization potential (in electron volts) are taken from the first paper listed unless otherwise designated. The following letters indicate sources frequently quoted:

B—Bomke, *Vakuumspektroskopie* (Leipzig, 1937).
BG—Bacher and Goudsmit, *Atomic Energy States* (New York, 1932).
E—Edlén, Monograph.
E1—Edlén, Zeits. f. Physik **104**, 188 (1937).
E2—Edlén, Zeits. f. Physik **104**, 407 (1937).
KS—Kruger and Shoupp, Phys. Rev. **46**, 124 (1934).
KW1—Kruger and Weissberg, Phys. Rev. **48**, 659 (1935).
KW2—Kruger and Weissberg, Phys. Rev. **52**, 314 (1937).
M—Moore, *Term Designations for Excitation Potentials* (Princeton, 1934).
R—Robinson, Phys. Rev. **51**, 14 (1937).
RM—Russell and Meggers, Bur. Stand. J. Res. **9**, 625 (1932).
S—Söderquist, Monograph.

Hydrogen 1

H I I.P. 13.530(E)

Paschen, Preuss. Akad. Wiss. Berlin Ber. **30**, 662 (1929). λ1215 series calculated wave-lengths. See Appendix B, Table III.

Suga, Sci. Pap. Inst. Phys. Chem. Research Tokyo **34**, 7 (1937). λ914–λ938, 18 lines class. **(A)**

K. R. Rao and Badami, Proc. Roy. Soc. **A138**, 540 (1932). λ915–λ950, 12 lines class., excitation conditions.

Frerichs, Ann. d. Physik (10) **19**, 1 (1933). λ1215 series, Stark effect.

Frerichs and Bomke, Physik. Zeits. **35**, 349 (1934), **35**, 549 (1934). λ1215 series, Stark effect.

The molecular spectrum of hydrogen is "many lined" rather than band, and may easily be mistaken for a line spectrum. See Section X.

Helium 2

He I I.P. 24.465(E), 24.463(R)

Paschen, Preuss. Akad. Wiss. Berlin Ber. p. 662 (1929). λ506–λ591. 12 lines class. **(A)**

Kruger, Phys. Rev. **36**, 855 (1930). λ320–λ601, 3 lines class., excitation conditions. **(B)**

Suga, Sci. Pap. Inst. Phys. and Chem. Research Tokyo **34**, 7 (1937). λ506–λ584, 14 lines class. λ510–λ601, 2 intersystem combinations and 7 forbidden lines. Considerable details of line profiles, reversals and bands, but wave-lengths seem erratic. **(C)**

Bomke, Physik. Zeits. **36**, 158 (1935). Stark effect observations. No splitting in λ584 series, $S-S$ and $S-D$ lines appear.

Helium has some bands in its molecular spectrum which, under low dispersion, may appear to be lines. See Section X.

He II I.P. 54.144 (E)

Paschen, Preuss. Akad. Wiss. Berlin Ber. p. 662 (1929). Calculated wave-lengths, λ1640 and λ303 series. See Appendix B, Table III.

Suga, Sci. Pap. Inst. Phys. and Chem. Research Tokyo **34**, 7 (1937). λ228–λ303, 13 lines class. **(A)**

Lyman, Astrophys. J. **60**, 1 (1924). 3 members of λ1640, 2 of λ303 series. **(C)**

Kruger, Phys. Rev. **36**, 855 (1930). λ230–λ303, 9 lines class., considerable discrepancies between observed and calculated wave-lengths. **(C)**

Lithium 3

Li I (L) I.P. 5.364(E)
Li II I.P. 75.256, 75.259*

Edlén, Monograph (1934) p. 31. λ172–λ199, 3 lines class. **(B)**

*Robinson, Phys. Rev. **51**, 14 (1937). λ172–λ199, 3 lines class. **(B)**

Werner, Nature **116**, 574 (1925), **118**, 154 (1926). λ1198–λ1754, 5 lines class. **(C)**

Ericson and Edlén, Zeits. f. Physik **59**, 656 (1930). λ172–λ199, 3 lines class. provisional wave-lengths included in Monograph.

Werner, Studies over Spektroskopiske Lyskilder, Copenhagen, 1927. Thesis not available, quoted by Ericson and Edlén as listing two additional lines, λ1166 and λ1132.

Lithium 3 (*continued*)

Li III I.P. 121.840

Edlén, Monograph (1934) p. 28. λ108–λ135, 3 lines, wave-length given calculated. (**B**)

Ericson and Edlén, Nature **125**, 233 (1930). λ114–λ135, 2 lines class. (**C**)

Gale and Hoag, Phys. Rev. **37**, 1703 (1931). λ104–λ135, 5 lines "Lyman Series." λ729, first line "Balmer Series." (**C**)

Beryllium 4

Be I I.P. 9.276 (E), 9.281

Paschen and Kruger, Ann. d. Physik (5) **8**, 1005 (1931). λ1487–λ1998, 11 lines class. (**A**)

Whitelaw and Mack. Phys. Rev. **47**, 677 (1935); terms.

Be II I.P. 18.119 (E), 18.13*

Paschen and Kruger, Ann. d. Physik (5) **8**, 1005 (1931). λ726–λ1776, 18 lines class. (**A**)

*Edlén and Ericson, Zeits. f. Physik **59**, 656 (1930). λ1036–λ1143, 2 lines class. (**B**)

Bowen and Millikan, Phys. Rev. **28**, 256 (1926). λ842–λ1776, 8 lines class. (**C**)

Be III I.P. 153.118*, 153.012†, 153.108‡

Edlén, Nature **127**, 405 (1931). λ82–λ100, 5 lines class. (**B**)

*Robinson, Phys. Rev. **51**, 14 (1937). λ82–λ100, 6 lines class. (**B**)

†Kruger and Cooper, Phys. Rev. **44**, 418 (1933). λ85–λ100, 3 lines class. (**B**)

‡Edlén, Phys. Rev. **44**, 778 (1933), Monograph (1934) p. 31. λ85–λ100, 3 lines class. (**B**)

Be IV I.P. 216.628*

Robinson, Phys. Rev. **50**, 99 (1936). λ58–λ76, 6 lines, wave-length given calculated. (**B**)

Edlén, Nature **127**, 405 (1931). λ64, λ76—2 lines, wave-length given calculated included in Monograph. (**B**)

*Edlén, Monograph (1934) p. 28. λ64, λ76—2 lines observed, calculated wave-lengths for 3 lines, λ61–λ76. (**B**)

Boron 5

B general

Selwyn, Proc. Phys. Soc. **41**, 392 (1929). λ1558–λ1843, 18 lines, 14 class., B I, II. (**C**)

B I I.P. 8.245 (E)

Selwyn, Proc. Phys. Soc. **41**, 392 (1929). λ1567–λ1827, 10 lines class. (**C**)

B II I.P. 24.998

Edlén, Monograph (1934) p. 52. λ694–λ1843, 18 lines class. (**A**)

Edlén, Zeits. f. Physik **73**, 476 (1931). λ694–λ1843, 17 lines class. provisional wave-lengths, included in Monograph.

B III I.P. 37.740

Edlén, Monograph (1934) p. 37. λ412–λ759, 8 lines class. (**A**)

Ericson and Edlén, Zeits. f. Physik **59**, 656 (1930). λ376–λ759, 11 lines class. (**C**)

Edlén, Zeits. f. Physik **72**, 763 (1931). λ518–λ759, 5 lines class. provisional wave-length included in Monograph.

B IV I.P. 258.028, 258.064*

Edlén, Nature **127**, 405 (1931), Monograph (1934) p. 31. λ53, λ60—2 lines class. (**B**)

*Robinson, Phys. Rev. **51**, 14 (1937). λ49–λ60, 4 lines class. (**B**)

B V I.P. 338.525*

Edlén, Nature **127**, 405 (1931). λ49, 1 line, wave-length given calculated, included in Monograph. (**B**)

*Edlén, Monograph (1934) p. 28. λ49, 1 line observed, calculated wave-length for 3 lines—λ39–λ49. (**B**)

Carbon 6

C I I.P. 11.212, 11.203*

Paschen and Kruger, Ann. d. Physik (5) **7**, 1 (1930). λ1112–λ1994, 113 lines class. (**A**)

*Edlén, Monograph (1934) p. 104. λ945–λ946, 3 lines class. (**A**) λ1112–λ1602, 67 lines, λPaschen and Kruger, classification of some lines changed.

Edlén, Zeits. f. Physik **85**, 85 (1933). λ945–λ1659, 15 lines. (**B**)

Boyce and Rieke, Phys. Rev. **47**, 653 (1935). λ945–λ1931, 26 lines. (**B**)

Webber and Watson, J. Opt. Soc. Am. **26**, 307 (1936). λ1140–λ1931, 10 lines. (**B**)

More and Rieke, Phys. Rev. **50**, 1054 (1936). λ1329–λ1658, 14 lines. (**B**)

Fowler and Selwyn, Proc. Roy. Soc. **A118**, 34 (1928). λ1260–λ1932, 22 lines class. (**C**)

Edlén, Zeits. f. Physik **84**, 746 (1933); terms.

Ufford, Phys. Rev. **53**, 568 (1938); Terms.

C II I.P. 24.260

Edlén, Monograph (1934), p. 74. λ425–λ1761, 96 lines class. (**A**) λ1988, 1 line, λFowler and Selwyn (Proc. Roy. Soc. **A120**, 312 (1928).

Edlén, Zeits. f. Physik **85**, 85 (1933). λ425–λ1761, 96 lines included in Monograph. (**B**)

Boyce and Rieke, Phys. Rev. **47**, 653 (1935). λ858–λ1761, 21 lines. (**B**)

Webber and Watson, J. Opt. Soc. Am. **26**, 307 (1936). λ1335, λ1336, 2 lines. (**B**)

More and Rieke, Phys. Rev. **50**, 1054 (1936). λ1335, λ1336—2 lines. (**B**)

Edlén, Zeits. f. Physik **84**, 746 (1933); Terms.

Carbon 6 (*continued*)

C III I.P. 47.637

Edlén, Zeits. f. Physik **85**, 85 (1933), Monograph (1934) p. 51. λ265–λ1923, 151 lines, classifications Monograph. (**A**)

Kruger and Shoupp, Phys. Rev. **44**, 105 (1933). λ459–λ535, 6 lines class. (**B**)

Boyce and Rieke, Phys. Rev. **47**, 653 (1935). λ977–λ1247, 8 lines. (**B**)

Fowler and Selwyn, Proc. Roy. Soc. **A120**, 312 (1928). λ1894–λ1980, 3 lines. (**C**)

Bowen, Phys. Rev. **38**, 128 (1931). λ319–λ1531, 49 lines class. (**C**)

Edlén, Zeits. f. Physik **84**, 746 (1933); Terms.

Whitelaw and Mack, Phys. Rev. **47**, 677 (1935); Terms.

C IV I.P. 64.169

Edlén, Monograph (1934) p. 40. λ198–λ1551, 43 lines class. (**A**)

Edlén, Zeits. f. Physik **85**, 85 (1933). λ200–λ1551, 41 lines included in Monograph. (**B**)

Boyce and Rieke, Phys. Rev. **47**, 653 (1935). λ1548–λ1551—2 lines. (**B**)

Edlén, Zeits. f. Physik **84**, 746 (1933); Terms.

C V I.P. 390.018*, 390.120†

Edlén, Nature **127**, 405 (1931). λ40, 1 line class. included in Monograph. (**B**)

Siegbahn and Söderman, Nature **129**, 21 (1932). λ34–λ40, 3 lines class. (**B**)

Edlén, Zeits. f. Physik **85**, 85 (1933). λ249, 2 lines class. included in Monograph. (**B**)

*Edlén, Monograph (1934) p. 31. λ40–λ249, 3 lines class. (**B**)

†Robinson, Phys. Rev. **51**, 14 (1937). λ33–λ40, 4 lines class. (**B**)

C VI I.P. 487.550*

Siegbahn and Söderman, Nature **129**, 21 (1932). λ34, 1 line, wave-length given calculated. (**B**)

*Edlén, Monograph (1934) p. 28. 3 calculated lines λ30–λ34.

Nitrogen 7

N I I.P. 14.460(E)

Ekefors, Zeits. f. Physik **63**, 437 (1930). λ1009–λ1889, 130 lines, 51 class. (**A**)

Edlén, Zeits. f. Physik **85**, 85 (1933). λ1134–λ1201, 6 lines. (**B**)

Boyce and Rieke, Phys. Rev. **47**, 653 (1935). λ1134–λ1745, 12 lines. (**B**)

Webber and Watson, J. Opt. Soc. Am. **26**, 307 (1936). λ1134–λ1745, 21 lines. (**B**)

More and Rieke, Phys. Rev. **50**, 1054 (1936). λ1134–λ1495, 17 lines. (**B**)

Kamiyama, Sci. Pap. Inst. Chem. and Phys. Research Tokyo, No. 933, p. 375. λ850–λ1850, 120 new lines, some class.

N II I.P. 29.443

Edlén, Monograph (1934) p. 109. λ453–λ1086, 64 lines class. included in Zeits. f. Physik **85**, 85 (1933). (**A**) λ1275–λ1277, 3 lines λ and classification Bowen, Phys. Rev. **29**, 231 (1927). λ1343–λ1887, 14 lines λ and classifications Fowler and Freeman (see below).

Edlén, Zeits. f. Physik **85**, 85 (1933). λ453–λ1086, 66 lines. (**B**)

Boyce and Rieke, Phys. Rev. **47**, 653 (1935). λ776–λ1086, 9 lines. (**B**)

Webber and Watson, J. Opt. Soc. Am. **26**, 307 (1936). λ1084–λ1743, 13 lines. (**B**)

More and Rieke, Phys. Rev. **50**, 1054 (1936). λ1084–λ1085, 2 lines. (**B**)

Fowler and Freeman, Proc. Roy. Soc. **A114**, 662 (1927). λ533–λ1887, 39 lines, 19 class. (**C**)

Freeman, Proc. Roy. Soc. **A124**, 654 (1929). λ1841–λ1887, 10 lines class. (**C**)

Edlén, Zeits. f. Physik **84**, 746 (1933); terms.

N III I.P. 47.201

Edlén, Monograph (1934) p. 78. λ265–λ1185, 98 lines class. (**A**) λ1387–λ1921, 15 lines class. λFreeman (see below).

Edlén, Zeits. f. Physik **85**, 85 (1933). λ265–λ1185, 98 lines, included in Monograph. (**B**)

Cady, Phys. Rev. **44**, 821 (1933). λ305–λ434, 3 lines class. (**B**)

Boyce and Rieke, Phys. Rev. **47**, 653 (1935). λ990, λ992, 2 lines. (**B**)

Freeman, Proc. Roy. Soc. **A121**, 318 (1928). λ1324–λ1954, 48 lines, 32 class. (**C**)

Edlén, Zeits. f. Physik **84**, 746 (1933); Terms.

Edlén, Zeits. f. Physik **98**, 561 (1936). Classifications, corrections to Monograph.

N IV I.P. 77.038

Edlén, Monograph (1934) p. 62. λ182–λ1719, 65 lines class. (**A**)

Edlén, Zeits. f. Physik **85**, 85 (1933). λ182–λ955, 64 lines, included in Monograph. (**B**)

Cady, Phys. Rev. **44**, 821 (1933). λ283–λ323, 5 lines class. (**B**)

Edlén, Zeits. f. Physik **73**, 476 (1931). λ1131–λ1168, 3 lines class. (**C**)

Edlén, Zeits. f. Physik **84**, 746 (1933); Terms.

N V I.P. 97.397*

Cady, Phys. Rev. **44**, 821 (1933). λ134–λ266, 24 lines class. (**B**)

*Edlén, Zeits. f. Physik **85**, 85 (1933); Monograph (1934) p. 41. λ140–λ1243, 18 lines, classifications Monograph. (**B**)

Edlén, Zeits. f. Physik **84**, 746 (1933); Terms.

N VI I.P. 549.081(E), 549.41(R)

N VII I.P. 663.728(E)

Oxygen 8

O general

Edlén, Zeits. f. Physik **85**, 85 (1933). λ188–λ663, 7 lines. **(B)**

O I I.P. 13.549(E)

Hopfield, Phys. Rev. **37**, 160 (1931). λ1302–λ1306, 3 lines class. **(B)**

Edlén, Zeits. f. Physik **85**, 85 (1933). λ878–λ1152, 6 lines. **(B)**

Boyce and Rieke, Phys. Rev. **47**, 653 (1935). λ935–λ1306, 11 lines. **(B)**

Webber and Watson, J. Opt. Soc. Am. **26**, 307 (1936). λ1305, 1 line. **(B)**

More and Rieke, Phys. Rev. **50**, 1054 (1936). λ972–λ1306, 12 lines. **(B)**

Frerichs, Phys. Rev. **36**, 398 (1930). λ748–λ1218, 34 lines, 21 class. (C)

O II I.P. 34.941

Edlén, Monograph (1934) p. 136. λ377–λ834, 84 lines class., included in Zeits. f. Physik **85**, 85 (1933). **(A)**

Edlén, Zeits. f. Physik **85**, 85 (1933). λ377–λ834, 86 lines. **(B)**

Edlén, Zeits. f. Physik **93**, 726 (1935). λ740–λ741, 3 lines class. **(B)**

Boyce and Rieke, Phys. Rev. **47**, 653 (1935). λ581–λ834, 8 lines. **(B)**

More and Rieke, Phys. Rev. **50**, 1054 (1936). λ833–λ834, 3 lines. **(B)**

Fowler, Proc. Roy. Soc. **A110**, 476 (1926). λ1956–λ1964, 5 lines classified by Bowen, Phys. Rev. **29**, 231 (1927). (C)

Edlén, Zeits. f. Physik **84**, 746 (1933); Terms.

O III I.P. 54.625

Edlén, Monograph (1934) p. 115. λ226–λ1154, 161 lines class. included in Zeits. f. Physik **85**, 85 (1933). **(A)**

Edlén, Zeits. f. Physik **85**, 85 (1933). λ226–λ1154, 168 lines. **(B)**

Kruger and Shoupp, Phys. Rev. **44**, 105 (1933). λ303–λ374, 17 lines class. **(B)**

Cady, Phys. Rev. **44**, 821 (1933). λ359, 3 lines class. **(B)**

Edlén, Zeits. f. Physik **93**, 726 (1935). λ554–λ659, 4 lines class. **(B)**

Boyce and Rieke, Phys. Rev. **47**, 653 (1935). λ600–λ899, 6 lines. **(B)**

Fowler, Proc. Roy. Soc. **A117**, 317 (1928). λ1903–λ1917, 3 lines class. (C)

Edlén, Zeits. f. Physik **84**, 746 (1933); Terms.

O IV I.P. 77.026

Edlén, Monograph (1934) p. 87. λ152–λ1344, 201 lines class. included in Zeits. f. Physik **85**, 85 (1933). **(A)**

Edlén, Zeits. f. Physik **85**, 85 (1933). λ152–λ1344, 205 lines. **(B)**

Kruger and Shoupp, Phys. Rev. **44**, 105 (1933). λ231–λ280, 23 lines class. **(B)**

Cady, Phys. Rev. **44**, 821 (1933). λ174–λ196, 6 lines class. **(B)**

Edlén, Zeits. f. Physik **93**, 726 (1935). λ153–λ279, 9 lines class. **(B)**

Edlén, Zeits. f. Physik **84**, 746 (1933); Terms.

Whitelaw and Mack, Phys. Rev. **47**, 677 (1935); Terms.

O V I.P. 113.298

Edlén, Zeits. f. Physik **85**, 85 (1933), Monograph (1934) p. 62. λ122–λ1371, 108 lines, classifications. Monograph. **(A)**

Kruger and Shoupp, Phys. Rev. **44**, 105 (1933). λ151–λ215, 9 lines class. **(B)**

Cady, Phys. Rev. **44**, 821 (1933). λ134–λ774, 26 lines class. **(B)**

Edlén, Zeits. f. Physik **73**, 476 (1931). λ630–λ966, 6 lines class. (C)

Edlén, Zeits. f. Physik **84**, 746 (1933); Terms.

O VI I.P. 137.424

Edlén, Zeits. f. Physik **85**, 85 (1933), Monograph (1934) p. 44. λ104–λ1038, 24 lines, classifications. Monograph. **(A)**

Edlén, Zeits. f. Physik **84**, 746 (1933); Terms.

O VII I.P. 735.218(E), 735.74(R)

O VIII I.P. 867.087(E)

Fluorine 9

F general

Edlén, Zeits. f. Physik **94**, 47 (1935). λ87–λ1140, 525 lines, 516 assigned as below. **(B)**

F I I.P. 17.34

Edlén, Zeits. f. Physik **93**, 433 (1935). λ952–λ959, 4 lines class. **(B)**

Edlén, Zeits. f. Physik **94**, 47 (1935). λ807–λ959, 6 lines. **(C+B)**

Bowen, Phys. Rev. **29**, 231 (1927). λ807–λ958, 6 lines class. (C)

F II I.P. 34.81*

Bowen, Phys. Rev. **45**, 82 (1934). λ353–λ608, 41 lines class. **(B)**

*Edlén, Zeits. f. Physik **94**, 47 (1935). λ349–λ608, 35 lines. **(B)**

Dingle, Proc. Roy. Soc. **A128**, 600 (1930). λ1702–λ1747, 5 lines class. (C)

Edlén, Zeits. f. Physik **93**, 433 (1935); Terms.

F III I.P. 62.35

Bowen, Phys. Rev. **45**, 82 (1934). λ215–λ1104, 59 lines class. **(B)**

Edlén, Zeits. f. Physik **93**, 433 (1935); **94**, 47 (1935). λ215–λ743, 96 lines, classifications Zeits. f. Physik **93**. **(A)**

F IV I.P. 87.34, 86.72*

Bowen, Phys. Rev. **45**, 82 (1934). λ200–λ679, 29 lines class. **(B)**

*Edlén, Zeits. f. Physik **92**, 19 (1934); **94**, 47 (1935). λ141–λ679, 169 lines, classifications Zeits. f. Physik **92**. **(A)**

Fluorine 9 (*continued*)

F V I.P. 113.670

Edlén, Zeits. f. Physik **89**, 597 (1934). λ120–λ1088, 123 lines class. **(A)**

Edlén, Zeits. f. Physik **94**, 47 (1935). λ120–λ1088, 123 lines, same as Zeits. f. Physik **89**. λ122–λ197, 16 lines class. **(B)**

F VI I.P. 156.369

Edlén, Zeits. f. Physik **89**, 179 (1934); **94**, 47 (1935). λ99–λ1140, 57 lines, classifications Zeits. f. Physik **89**. **(A)**

F VII I.P. 184.261

Edlén, Zeits. f. Physik **89**, 179 (1934); **94**, 47 (1935). λ87–λ135, 9 lines, classifications Zeits. f. Physik **89**. **(A)**

F VIII

Flemberg, Zeits. f. Physik **111**, 747 (1939). λ16, 2 lines, class. (Wave-lengths in X-units.) **(B)**

Neon 10

Ne I I.P. 21.47

Boyce, Phys. Rev. **46**, 378 (1934). λ743–λ587, 16 lines class. **(A)**

Suga, Sci. Pap. Inst. Phys. and Chem. Research Tokyo **34**, 7 (1937). λ743–λ576, 32 lines class. Excitation studies. **(C)**

Ne II I.P. 40.91

Boyce, Phys. Rev. **46**, 378 (1934). λ324–λ1938, 46 lines class. **(A)**

Ne III I.P. 63.3

Boyce, Phys. Rev. **46**, 378 (1934). λ282–λ1257, 17 lines class. **(A)**

von Keussler, Zeits. f. Physik **85**, 1 (1933). λ251–λ313, 13 lines class. **(B)**

Ne IV I.P. (97)

Boyce, Phys. Rev. **46**, 378 (1934). λ358–λ543, 11 lines class. The doublets in this spectrum are very close and require considerably better resolving power. **(C)**

Ne V

Paul, Phys. Rev. **56**, 1067 (1939). λ480–λ572, 7 lines class. **(C)**

Sodium 11

Na general

Söderquist, Monograph (1934) p. 13. λ105–λ516, 19 lines. **(B)**

Na I (L) I.P. 5.113(S)
Na II I.P. 47.065

Söderquist, Monograph (1934) p. 26. λ281–λ376, 6 lines class. **(B)**

Vance, Phys. Rev. **41**, 480 (1932). λ270–λ302, 9 lines class. **(C)**

Na III I.P. 71.307*

Söderquist, Zeits. f. Physik **76**, 316 (1932). λ188–λ381, 26 lines class., included in Monograph. **(B)**

*Söderquist, Monograph (1934), p. 43. λ183–λ1986, 41 lines class. **(B)**

Tomboulian, Phys. Rev. **54**, 347 (1938). λ1100–λ1996, 106 lines class. **(B)**

Vance, Phys. Rev. **41**, 480 (1932). λ230–λ273, 9 lines class. **(C)**

Na IV I.P. 98.409*

Söderquist, Zeits. f. Physik **79**, 634 (1932). λ150–λ413, 43 lines class., included in Monograph. **(B)**

* Söderquist, Monograph (1934) p. 54. λ129–λ413, 72 lines class. **(B)**

Vance, Phys. Rev. **41**, 480 (1932). λ320–λ412, 7 lines class. **(C)**

Na V I.P. 137.638

Söderquist, Monograph (1934) p. 68. λ106–λ515, 72 lines class. **(B)**

Na VI I.P. 171.374

Söderquist, Monograph (1934) p. 79. λ88–λ639, 62 lines class. **(B)**

Na VII I.P. 208.235

Söderquist, Monograph (1934) p. 89. λ86–λ492, 33 lines class. **(B)**

Na VIII I.P. 262.969

Söderquist, Monograph (1934) p. 96. λ77–λ497, 15 lines class. **(B)**

Na IX I.P. 298.388

Söderquist, Monograph (1934) p. 100. λ77–λ682, 3 lines class. **(B)**

Magnesium 12

Mg general

Söderquist, Monograph (1934) pp. 16, 101. λ68–λ491, 21 lines; λ1579–λ1975, 10 lines. **(B)**

Mg I I.P. 7.608(S)

Selwyn, Proc. Phys. Soc. **41**, 392 (1929). λ1668–λ1828, 5 lines class. **(C)**

Mg II I.P. 14.959(S)

Lyman, Science **60**, 388 (1924). λ947–λ1241, 4 lines class **(C)**

Mg III I.P. 79.736

Söderquist, Monograph (1934) p. 27. λ182–λ1979, 58 lines class. **(A)**

Söderquist, Zeits. f. Physik **79**, 634 (1932). λ164–λ234, 12 lines class. included in Monograph. **(B)**

Magnesium 12 (*continued*)

Mg IV I.P. 108.774

Söderquist, Monograph (1934) p. 44. λ123–λ1957, 73 lines class. **(A)**

Söderquist, Zeits. f. Physik **76**, 756 (1932). λ137–λ324, 38 lines class. **(B)**

Mg V I.P. 140.466*

Söderquist, Zeits. f. Physik **79**, 634 (1932). λ110–λ356, 39 lines class. included in Monograph. **(B)**

*Söderquist, Monograph (1934) p. 55. λ95–λ356, 53 lines class. **(B)**

Mg VI I.P. 185.566

Söderquist, Monograph (1934) p. 69. λ79–λ404, 46 lines class. **(B)**

Mg VII I.P. 224.309

Söderquist, Monograph (1934) p. 80. λ79–λ435, 29 lines class. **(B)**

Mg VIII I.P. 265.580

Söderquist, Monograph (1934) p. 89. λ74–λ437, 18 lines class. **(B)**

Mg IX I.P. 326.507

Söderquist, Monograph (1934) p. 96. λ67–λ444, 9 lines class. **(B)**

Absorption

Kremenewsky, Physik. Zeits. d. Sowjetunion **2**, 491 (1931). λ1629–λ1826, 15 lines class.

Aluminum 13

Al general

Söderquist, Monograph (1934) p. 17 and 101. λ58–λ229, 21 lines. λ1150–λ1464, 13 lines. **(B)**

Al I I.P. 5.956(S)

Selwyn, Proc. Phys. Soc. **41**, 392 (1929). λ1763–λ1769, 3 lines, class. *pp'* group. **(C)**

Al II I.P. 18.733(S)

Zumstein, Phys. Rev. **38**, 2214 (1931). λ1670–λ1863, 12 lines class. **(B)**

Sawyer and Paschen, Ann. d. Physik **84**, 1 (1927). λ933–λ1991, 99 lines, 92 class. **(C)**

Paschen, Ann. d. Physik (5) **12**, 509 (1932). λ1858–λ1889, 4 lines class. Classifications and corrections to Ann. d. Physik **84**. **(C)**

Pincherle, Accad. dei Lincei **16**, 35 (1932). Perturbed lines in Al II. Journal not available.

Al III I.P. 28.306(S)

Zumstein, Phys. Rev. **38**, 2214 (1931). λ1854, λ1863, 2 lines class. **(B)**

Ekefors, Zeits. f. Physik **51**, 471 (1928). λ487–λ1863, 21 lines class. **(B)**

Al IV I.P. 119.386

Söderquist, Monograph (1934) p. 29. λ85–λ1881, 66 lines class. **(A)**

Söderquist, Zeits. f. Physik **79**, 634 (1932). λ111–λ162, 12 lines class. **(B)**

Al V I.P. 153.109*

Söderquist, Zeits. f. Physik **76**, 756 (1932). λ95–λ281, 38 lines class. included in Monograph. **(B)**

*Söderquist, Monograph (1934) p. 45. λ86–λ282, 56 lines class. **(B)**

Al VI I.P. 189.347*

Söderquist, Zeits. f. Physik **79**, 634 (1932). λ87–λ313, 30 lines class. included in Monograph. **(B)**

*Söderquist, Monograph (1934) p. 56. λ70–λ313, 44 lines, 42 class. **(B)**

Al VII I.P. 240.450

Söderquist, Monograph (1934) p. 70. λ62–λ357, 34 lines class. **(B)**

Al VIII I.P. 283.747

Söderquist, Monograph (1934) p. 80. λ64–λ387, 19 lines class. **(B)**

Al IX I.P. 330.465

Söderquist, Monograph (1934) p. 90. λ60–λ393, 6 lines class. **(B)**

Al X I.P. 397.177

Söderquist, Monograph (1934) p. 96. λ55–λ333, 5 lines class. **(B)**

Silicon 14

Si general

Söderquist, Monograph (1934) p. 18. λ62–λ79, 3 lines. **(B)**

Si I I.P. 8.077(S), 8.11

Kiess, J. Research Nat. Bur. Stand. **21**, 185 (1938). λ1565–λ1991, 148 lines class. **(A)**

Fowler, Proc. Roy. Soc. **A123**, 422 (1929). λ1590–λ1992, 133 lines, 70 class. **(C)**

Si II I.P. 16.261(S)

Zumstein, Phys. Rev. **38**, 2214 (1931). λ1527–λ1817, 4 lines class. **(B)**

Bowen, Phys. Rev. **39**, 8 (1932). λ1246–λ1354, 9 lines class. **(B)**

Kiess, J. Research Nat. Bur. Stand. **21**, 185 (1938). λ1527–λ1817, 5 lines class. **(B)**

Bowen and Millikan, Phys. Rev. **26**, 150 (1925). λ1190–λ1197, 4 lines class. **(C)**

Fowler, Phil. Trans. Roy. Soc. **A225**, 1 (1925). λ990–λ1818, 17 lines class. **(C)**

Bowen, Phys. Rev. **31**, 34 (1928). λ1246–λ1309, 6 lines class. **(C)**

Silicon 14 (*continued*)

Si III I.P. 33.329(S)

Bowen, Phys. Rev. **39**, 8 (1932). λ566–λ1896, 59 lines class. (**A**)

Si IV I.P. 44.915

Edlén and Söderquist, Zeits. f. Physik **87**, 217 (1933). λ815–λ1798, 11 lines class. (**A**)

Si V I.P. 165.660

Söderquist, Monograph (1934) p. 30. λ85–λ119, 9 lines class. (**B**)

Si VI I.P. 203.835

Söderquist, Monograph (1934) p. 46. λ77–λ250, 25 lines, 22 class. (**B**)

Si VII I.P. 244.635

Söderquist, Monograph (1934) p. 56. λ68–λ279, 21 lines class. (**B**)

Si VIII I.P. 302.720

Söderquist, Monograph (1934) p. 70. λ61–λ320, 16 lines class. (**B**)

Absorption

Takamine, Suga and Kamiyama, Sci. Pap. Inst. Phys. and Chem. Research Tokyo **33**, 247 (1937). λ1630–λ2000.

Phosphorus 15

P general

Queney, J. de phys. et rad. (6) **10**, 299 (1929). λ1189–λ1987, 196 lines. (C)

P I I.P. 10.9

Robinson, Phys. Rev. **49**, 297 (1936). λ1324–λ1908, 41 lines class. (**B**)

P II I.P. 19.59

Robinson, Phys. Rev. **49**, 297 (1936). λ783–λ1880, 102 lines class. (**A**)

Robinson, Phys. Rev. **51**, 726 (1937). λ927–λ930, 3 lines class. corrections to Phys. Rev. **49**. (**B**)

P III I.P. 30.012

Robinson, Phys. Rev. **51**, 726 (1937). λ497–λ1758, 88 lines class. (**A**)

Bowen, Phys. Rev. **39**, 8 (1932). λ781–λ978, 24 lines class. (**B**)

P IV I.P. 51.106

Robinson, Phys. Rev. **51**, 726 (1937). λ283–λ1910, 88 lines class. (**A**)

Bowen, Phys. Rev. **39**, 8 (1932). λ628–λ1910, 46 lines class. (**B**)

P V I.P. 69.698

Robinson, Phys. Rev. **51**, 726 (1937). λ210–λ1611, 31 lines class. (**A**)

Sulphur 16

S general

Bloch and Bloch, J. de phys. et rad. (7) **6**, 441 (1935). λ328–λ1259, 404 lines, 147 assigned as below. (**B**)

Lacroute, J. de phys. et rad. (6) **9**, 180 (1928). λ1251–λ1999, 50 lines. (**C**)

S I I.P. 10.31(M)

Ruedy, Phys. Rev. **44**, 757 (1933). λ1000–λ1915, 83 lines, 53 class. (**A**)

Bloch and Bloch, J. de phys. et rad. (7) **6**, 441 (1935). λ1204, 1 line. (**B**)

S II I.P. 23.3*

Bloch and Bloch, J. de phys. et rad. (7) **6**, 441 (1935). λ640–λ1260, 38 lines. (**B**)

*Ingram, Phys. Rev. **32**, 172 (1928). λ640–λ1260, 43 lines class. (**C**)

Gilles, Thèse Paris (1930) Ser. A No. 1285, 2154; Classifications.

S III I.P. 34.9*

Bloch and Bloch, J. de phys. et rad. (7) **6**, 441 (1935). λ475–λ1202, 55 lines, 15 class. (**B**)

Robinson, Phys. Rev. **52**, 724 (1937). λ500–λ1077, 17 lines class. (**B**)

*Ingram, Phys. Rev. **33**, 907 (1929). λ484–λ1391, 41 lines class. (**C**)

S IV I.P. 47.08(BG)

Bowen, Phys. Rev. **39**, 8 (1932). λ519–λ804, 21 lines class. (**B**)

Bloch and Bloch, J. de phys. et rad. (7) **6**, 441 (1935). λ519–λ1074, 42 lines, 6 class. (**B**)

Millikan and Bowen, Phys. Rev. **25**, 600 (1925). λ551–λ1745, 16 lines class. (**C**)

Bowen, Phys. Rev. **31**, 34 (1928). λ836–λ1297, 10 lines class. (**B**)

S V I.P. 63(BG)

Bowen, Phys. Rev. **39**, 8 (1932). λ437–λ906, 30 lines class. (**B**)

Bloch and Bloch, J. de phys. et rad. (7) **6**, 441 (1935). λ458–λ861, 11 lines. (**B**)

Bowen and Millikan, Phys. Rev. **25**, 591 (1925). λ873, λ876, 2 lines class. (**C**)

S VI I.P. 87.610

Robinson, Phys. Rev. **52**, 724 (1937). λ171–λ945, 26 lines class. (**A**)

Bowen and Millikan, Phys. Rev. **25**, 295 (1925). λ289–λ1118, 9 lines class. (**C**)

S VIII I.P.

Robinson, Phys. Rev. **52**, 724 (1937). λ199, λ203, 2 lines class. (**B**)

Chlorine 17

Cl general

Edlén, Zeits. f. Physik **100**, 726 (1936). λ40–λ48, 4 lines. **(B)**

Vaudet, Comptes rendus **185**, 1270 (1927). λ1298–λ1999, 59 lines. (C)

Cl I I.P. 12.96(BG)

Bowen, Phys. Rev. **31**, 497 (1928). λ1336–λ1364, 4 lines class. (C)

Cl II I.P. 23.70

Kiess and deBruin, J. Research Nat. Bur. Stand. **23**, 443 (1939). λ558–λ1923, 119 lines class. (C)

Murakawa, Zeits. f. Physik **109**, 162 (1938). Classifications.

Bowen, Phys. Rev. **31**, 34 (1928), λ634–1080, 26 lines class. (C)

Cl III I.P. 39.7(BG)

Bowen, Phys. Rev. **45**, 401 (1934). λ406–λ1984, 90 lines class. (A)

Bowen, Phys. Rev. **31**, 34 (1928). λ573–λ1015, 31 lines class. (C)

Cl IV I.P. 53.16(B)

Bowen, Phys. Rev. **45**, 401 (1934). λ318–λ1652, 43 lines class. **(B)**

Bowen, Phys. Rev. **46**, 377 (1934). λ332–λ757, 10 lines class. **(B)**

Bowen, Phys. Rev. **31**, 34 (1928). λ463–λ986, 26 lines class. (C)

Deb, Proc. Acad. Sci. U. P. India **2**, 43 (1932). Terms, journal not available.

Cl V I.P. 67.4(B)

Bowen, Phys. Rev. **45**, 401 (1934). λ286–λ556, 22 lines class. **(B)**

Millikan and Bowen, Phys. Rev. **25**, 600 (1925). λ538–λ639, 10 lines class. (C)

Bowen, Phys. Rev. **31**, 34 (1928). λ676–λ895, 17 lines class. (C)

Deb, Proc. Acad. Sci. U. P. India **2**, 43 (1932). Terms, journal not available.

Cl VI I.P. 88.6(B)

Bowen and Millikan, Phys. Rev. **25**, 591 (1925). λ671–λ737, 6 lines class. (C)

Parker and Phillips, Phys. Rev. **57**, 140 (1940). λ194–λ737, 23 lines class. **(B)**

Cl VII I.P. 113.73

Phillips, Phys. Rev. **53**, 248 (1938). λ174–λ813, 22 lines class. (A)

Cl VIII I.P. 346.6

Edlén, Zeits. f. Physik **100**, 726 (1936). λ39–λ60, 13 lines class. **(B)**

Cl IX I.P. 398.8

Edlén, Zeits. f. Physik **100**, 726 (1936). λ42–λ54, 35 lines class. **(B)**

Cl X I.P. 453.1

Edlén, Zeits. f. Physik **100**, 726 (1936). λ39–λ48, 15 lines class. **(B)**

Cl XI

Edlén, Zeits. f. Physik **100**, 726 (1936). λ40, λ41, 2 lines class. **(B)**

Argon 18

A I I.P. 15.69

Boyce, Phys. Rev. **48**, 396 (1935). λ866–λ1066, 6 lines class. (A)

Dorgelo and Abbink, Zeits. f. Physik **41**, 753 (1927). λ797–λ1066, 22 lines. (C)

A II I.P. 27.49*

Boyce, Phys. Rev. **48**, 396 (1935). λ487–λ1978, 80 lines class. (A)

*Edlén, Zeits. f. Physik **104**, 407 (1937). Corrections to Boyce (analysis, not wave-lengths).

A III I.P. 40.48*

von Keussler, Zeits. f. Physik **84**, 42 (1933). λ508–λ1836, 20 lines, 17 class. (A)

*Boyce, Phys. Rev. **48**, 396 (1935), **49**, 351 (1936). λ395–λ1973, 87 lines class. (A)

A IV I.P. (61)

Boyce, Phys. Rev. **48**, 396 (1935). λ396–λ1197, 26 lines class. **(B)**

de Bruin, Physica **3**, 809 (1936). Extension of analysis.

A V I.P. (78)

Boyce, Phys. Rev. **48**, 396 (1935). λ705–λ836, 10 lines class. Two multiplets. **(B)**

Parker and Phillips, Phys. Rev. **58**, 93 (1940). λ522–λ527. 3 lines class. **(B)**

A VI

Parker and Phillips, Phys. Rev. **58**, 93 (1940). λ544–λ596, 6 lines class. **(B)**

A VII

Parker and Phillips, Phys. Rev. **58**, 93 (1940). λ191–λ479, 9 lines class. **(B)**

A VIII

Parker and Phillips, Phys. Rev. **58**, 93 (1940). λ229–λ526, 7 lines class. **(B)**

Absorption

Beutler, Zeits. f. Physik **93**, 177 (1935). λ781–λ1067, 20 lines class.

Potassium 19

K general
Ekefors, Zeits. f. Physik **71**, 53 (1931). λ156–λ1034, 659 lines, 483 assigned as below. (**B**)

K I (L) I.P. 4.32(BG)
K II I.P. 31.67(KW), 31.7*
Ekefors, Zeits. f. Physik **71**, 53 (1931). λ261–λ613, 26 lines. (**B**)
*Bowen, Phys. Rev. **31**, 497 (1928). λ601–λ615, 4 lines class. (**C**)

K III I.P. 45.5*
Ekefors, Zeits. f. Physik **71**, 53 (1931). λ204–λ874, 77 lines. (**B**)
Bowen, Phys. Rev. **31**, 497 (1928). λ467–λ779, 6 lines class. (**C**)
Ram, Ind. J. Phys. **8**, 151 (1933). Classifications.
Kruger and Phillips, Phys. Rev. **51**, 1087 (1937). Classifications.
*Edlén, Zeits. f. Physik **104**, 407 (1937). Classifications.

K IV I.P. 62.5(B)
Ekefors, Zeits. f. Physik **71**, 53 (1931). λ166–λ1026, 62 lines. (**B**)
Bowen, Phys. Rev. **46**, 791 (1934). λ272–λ417, 19 lines class. (**B**)
Bowen, Phys. Rev. **31**, 497 (1928). λ737–λ755, 6 lines class. (**C**)
Ram, Ind. J. Phys. **8**, 151 (1933). Classifications.
Robinson, Phys. Rev. **52**, 724 (1937). Classifications.

K V
Ekefors, Zeits. f. Physik **71**, 53 (1931). λ213–λ1027, 131 lines. (**B**)
Bowen, Phys. Rev. **46**, 791 (1934). λ295–λ645, 26 lines class. (**B**)

K VI
Ekefors, Zeits. f. Physik **71**, 53 (1931). λ156–λ1000, 187 lines. (**B**)
Ram, Ind. J. Phys. **8**, 151 (1933). Classifications.
Whitford, Phys. Rev. **46**, 793 (1934). Classifications.
Robinson, Phys. Rev. **52**, 724 (1937). Classifications.

K VII
Whitford, Phys. Rev. **46**, 793 (1934). Classifications.

K VIII
Whitford, Phys. Rev. **46**, 793 (1934). Classifications.
Parker and Phillips, Phys. Rev. **57**, 140 (1940). λ156–λ573. 23 lines class. (**B**)

K IX I.P. 174.90
Edlén, Zeits. f. Physik **100**, 621 (1936). λ185–λ636, 6 lines class. (**A**)
Whitford, Phys. Rev. **46**, 793 (1934). Classifications.

K X I.P. 501.4
Edlén and Tyrén, Zeits. f. Physik **101**, 206 (1936). λ30–λ42, 11 lines class. (**B**)

K XI
Edlén and Tyrén, Zeits. f. Physik **101**, 206 (1936). λ32–λ38, 8 lines class. (**B**)

Absorption

Beutler and Guggenheimer, Zeits. f. Physik **87**, 188 (1933). λ653, λ662, 2 lines class.

Calcium 20

Ca general
Ekefors, Zeits. f. Physik **71**, 53 (1931). λ136–λ1035, 728 lines, 476 assigned as below. (**B**)

Ca I (L) I.P. 6.09(BG)
Ca II I.P. 11.82(BG)
Saunders and Russell, Astrophys. J. **62**, 51 (1925). λ1369–λ1851, 20 lines class. (**C**)
Selwyn, Proc. Phys. Soc. **41**, 392 (1929). λ1649–λ1841, 6 lines class. (**C**)

Ca III I.P. 51.0*
Ekefors, Zeits. f. Physik **71**, 53 (1931). λ242–λ1035, 94 lines. (**B**)
*Bowen, Phys. Rev. **31**, 497 (1928). λ404–λ2000, 64 lines class. (**C**)

Ca IV I.P. 67(E_1)
Ekefors, Zeits. f. Physik **71**, 53 (1931). λ249–λ1031, 52 lines. (**B**)
Kruger and Phillips, Phys. Rev. **51**, 1087 (1937). λ297–λ670, 16 lines class. (**B**)
Ram, Ind. J. Phys. **8**, 163 (1933). Classifications.

Ca V
Ekefors, Zeits. f. Physik **71**, 53 (1931). λ231–λ1022, 83 lines. (**B**)
Bowen, Phys. Rev. **46**, 791 (1934). λ184–λ387, 36 lines class. (**B**)
Bowen, Phys. Rev. **31**, 497 (1928). λ638–λ657, 6 lines class. (**C**)
Ram, Ind. J. Phys. **8**, 163 (1933). Classifications.

Ca VI
Ekefors, Zeits. f. Physik **71**, 53 (1931). λ228–λ1033, 102 lines. (**B**)
Bowen, Phys. Rev. **46**, 791 (1934). λ228–λ642, 31 lines class. (**B**)

Ca VII
Ekefors, Zeits. f. Physik **71**, 53 (1931). λ250–λ1034, 136 lines. (**B**)
Whitford, Phys. Rev. **46**, 793 (1934). Classifications.
Robinson, Phys. Rev. **52**, 724 (1937). Classifications.

Ca VIII
Whitford, Phys. Rev. **46**, 793 (1934). Classifications.

Calcium 20 (*continued*)

Ca IX
Edlén, Zeits. f. Physik **103**, 536 (1936). Classifications.
Parker and Phillips, Phys. Rev. **57**, 140 (1940). λ101–λ516. 25 lines class. **(B)**

Ca X I.P. 120.21
Edlén, Zeits. f. Physik **100**, 621 (1936). λ152–λ574, 6 lines class. **(A)**

Ca XI I.P. 589.0
Edlén and Tyrén, Zeits. f. Physik **101**, 206 (1936). λ25–λ36, 11 lines class. **(B)**

Ca XII
Edlén and Tyrén, Zeits. f. Physik **101**, 206 (1936). λ27–λ33, 9 lines class. **(B)**

Scandium 21

Sc general
Beckman, Thesis, Upsala (1937). λ62–λ1613, 770 lines, 189 assigned as below. **(B)**
McLennan and Liggett, Trans. Roy. Soc. Canada **20**, 377 (1926). λ1598–λ1994, 8 lines. **(C)**

Sc I (X) I.P. 6.7(BG)

Sc II (O) I.P. 12.8(BG)

Sc III I.P. 24.635(KW_2)
Beckman, Thesis, Upsala (1937). λ627–λ1610, 7 lines. **(B)**
Smith, Proc. Nat. Acad. Sci. **13**, 65 (1927). λ730–λ1994, 6 lines class. **(C)**

Sc IV I.P. 73.6*
Beckman, Thesis, Upsala (1937). λ216–λ376, 22 lines, 4 class. **(B)**
*Kruger, Weissberg and Phillips, Phys. Rev. **51**, 1090 (1937). λ215–λ298, 4 lines class. **(B)**

Sc V I.P. 91(E_2)
Beckman, Thesis, Upsala (1937). λ229–λ588, 21 lines, 13 class. **(B)**
Kruger and Phillips, Phys. Rev. **51**, 1087 (1937). λ229–λ588, 16 lines class. **(B)**

SC VI I.P. 110.5(E_1)
Beckman, Thesis, Upsala (1937). λ203–λ581, 31 lines, 23 class. **(B)**
Kruger and Pattin, Phys. Rev. **52**, 621 (1937). λ201–λ581, 29 lines class. **(B)**

Sc VII
Beckman, Thesis, Upsala (1937). λ183–λ568, 25 lines, 18 class. **(B)**
Kruger and Pattin, Phys. Rev. **52**, 621 (1937). λ186–λ571, 16 lines class. **(B)**

SC VIII
Beckman, Thesis, Upsala (1937). λ165–λ494, 15 lines, 13 class. **(B)**
Kruger and Phillips, Phys. Rev. **52**, 97 (1937). λ164–λ375, 15 lines class. **(B)**

Sc IX
Beckman, Thesis, Upsala (1937). λ119–λ538, 17 lines class. **(B)**
Kruger and Phillips, Phys. Rev. **52**, 97 (1937). λ318–λ427, 9 lines class. **(B)**

Sc X
Beckman, Thesis, Upsala (1937). λ76–λ628, 26 lines class. **(A)**
Parker and Phillips, Phys. Rev. **57**, 140 (1940). λ135–λ343. 12 lines class. **(B)**

Sc XI I.P. 248.58, 248.61*
Beckman, Thesis, Upsala (1937). λ62–λ169, 30 lines class. **(A)**
*Edlén, Zeits. f. Physik **100**, 621 (1936). λ95–λ169, 10 lines class. **(B)**

SC XII I.P. 683.4
Edlén and Tyrén, Zeits. f. Physik **101**, 206 (1936). λ27–λ31, 5 lines class. **(B)**

Titanium 22

Ti I (X) I.P. 6.81(BG)
Ti II I.P. 13.6
Russell, Astrophys. J. **66**, 283 (1927). λ1906–λ1914, 6 lines class. **(C)**

Ti III I.P. 27.6
Russell and Lang, Astrophys. J. **66**, 13 (1927). λ1002–λ1927, 55 lines class. **(C)**

Ti IV I.P. 43.06
Russell and Lang, Astrophys. J. **66**, 13 (1927). λ424–λ1469, 11 lines class. **(C)**

Ti V I.P. 99.7, 99.4*
Kruger and Weissberg, Phys. Rev. **48**, 659 (1935). λ225, λ229, 2 lines class. **(B)**
*Kruger, Weissberg and Phillips, Phys. Rev. **51**, 1090 (1937). λ163, λ164, 2 lines class. **(B)**

Ti VI I.P. 119
Edlén, Zeits. f. Physik **104**, 407 (1937). λ182–λ202, 10 lines class. **(B)**

Ti VII I.P. 140.1*
Kruger and Pattin, Phys. Rev. **52**, 621 (1937). λ500–λ522, 5 lines class. **(B)**
*Edlén, Zeits. f. Physik **104**, 188 (1938). λ164–λ179, 19 lines class. **(B)**

Ti VIII
Kruger and Pattin, Phys. Rev. **52**, 621 (1937). λ150–λ162, 15 lines class. **(B)**

Titanium 22 (*continued*)

Ti X
Edlén, Zeits. f. Physik **103**, 536 (1936). λ101, λ102, 2 lines class. (**B**)

Ti XI I.P. (264)
Edlén, Zeits. f. Physik **103**, 536 (1936). λ72–λ127, 14 lines class. (**A**)

Ti XII I.P. 290.08
Edlén, Zeits. f. Physik **100**, 621 (1936). λ61–λ117, 16 lines class. (**A**)

Ti XIII I.P. 784.6
Edlén and Tyrén, Zeits. f. Physik **101**, 206 (1936). λ23–λ27, 5 lines class. (**B**)

Vanadium 23

V general
Meggers and Moore, unpublished 1939. λ1248–λ2000 about 600 lines V II, III, IV.

V I I.P. 6.72(M)
Moore, Phys. Rev. **55**, 710 (1939). λ1873–λ2000, 43 lines, 30 class. (**C**)

V II I.P. 14.1(estimate)
Meggers, J. Research Nat. Bur. Stand. **25**, 83 (1940). λ1313–λ2000, 185 lines, 171 class. (**A**)

V III I.P. 29.6
White, Phys. Rev. **33**, 672 (1929). λ1118–λ1829, 74 lines class. (**C**)

V IV I.P. 48.3*
Ekefors, Zeits. f. Physik **71**, 53 (1931). λ675–λ680, 4 lines. (**B**)
*White, Phys. Rev. **33**, 538 (1929). λ675–λ1999, 57 lines class. (**C**)

V V I.P. 64.891(KW$_2$)
Ekefors, Zeits. f. Physik **71**, 53 (1931). λ286–λ485, 5 lines. (**B**)
Gibbs and White, Phys. Rev. **33**, 157 (1929). λ287–λ1717, 11 lines class. (**C**)

V VI I.P. 128.4
Kruger and Weissberg, Phys. Rev. **48**, 659 (1935). λ128–λ183, 4 lines class. (**B**)

V VII I.P. 150
Edlén, Zeits. f. Physik **104**, 407 (1937). λ148–λ165, 11 lines class. (**B**)

V VIII I.P. 172.8
Edlén, Zeits. f. Physik **104**, 188 (1937). λ135–λ148, 19 lines class. (**B**)

V IX
Kruger and Pattin, Phys. Rev. **52**, 621 (1937). λ125–λ127, 6 lines class. (**B**)

V XI
Edlén, Zeits. f. Physik **103**, 536 (1936). λ87, λ88, 2 lines class. (**B**)

V XII I.P. (307)
Edlén, Zeits. f. Physik **103**, 536 (1936). λ61–λ107, 15 lines class. (**A**)

V XIII I.P. 334.69
Edlén, Zeits. f. Physik **100**, 621 (1936). λ53–λ100, 15 lines class. (**A**)

V XIV I.P. 892.8
Edlén and Tyrén, Zeits. f. Physik **101**, 206 (1936). λ21–λ24, 4 lines class. (**B**)

Chromium 24

Cr general
Bloch and Bloch, J. de phys. et rad. (6) **6**, 105 (1925). λ1506–λ1926, 182 lines. (**C**)

Cr I (X) I.P. 6.74(BG)
Cr II I.P. 16.6(BG)
Kiess, unpublished 1939. λ1971–λ2000, 19 lines. (**B**)

Cr III I.P. 31(B)
Bowen, Phys. Rev. **52**, 1153 (1937). λ921–λ2000, 89 lines class. (**A**)
White, Phys. Rev. **33**, 914 (1929). λ1196–λ1736, 35 lines class. (**C**)

Cr IV I.P. 50.4
White, Phys. Rev. **33**, 672 (1929). λ617–λ1990, 65 lines class. (**C**)
Bowen, Phys. Rev. **52**, 1153 (1937). λ574–λ1968, 62 lines class. (**C**)

Cr V I.P. 72.8
White, Phys. Rev. **33**, 538 (1929). λ433–λ1820, 55 lines class. (**C**)

Cr VI I.P. 90.17
Kruger and Weissberg, Phys. Rev. **52**, 314 (1937). λ209, λ211, 2 lines class. (**B**)
Gibbs and White, Phys. Rev. **33**, 157 (1929). λ335–λ338, 3 lines class. (**C**)

Cr VII I.P. 160.4
Kruger and Weissberg, Phys. Rev. **48**, 659 (1935). λ104–λ149, 4 lines class. (**B**)

Cr VIII I.P. 184
Edlén, Zeits. f. Physik **104**, 407 (1937). λ124–λ136, 10 lines class. (**B**)

Cr IX I.P. 208.6
Edlén, Zeits. f. Physik **104**, 188 (1937). λ117–λ124, 11 lines class. (**B**)

Chromium 24 (*continued*)

Cr XII
Edlén, Zeits. f. Physik **103**, 536 (1936). λ76, 2 lines class. (**B**)

Cr XIII I.P. (353)
Edlén, Zeits. f. Physik **103**, 536 (1936). λ54–λ92, 14 lines class. (**A**)

Cr XIV I.P. 382.37
Edlén, Zeits. f. Physik **100**, 621 (1936). λ46–λ86, 16 lines class. (**A**)

Cr XV I.P. 1008.1
Edlén and Tyrén, Zeits. f. Physik **101**, 206 (1936). λ18–λ21, 4 lines class. (**B**)
Tyrén, Zeits. f. Physik **111**, 314 (1938). λ15–λ21, 9 lines class. (**A**)

Manganese 25

Mn general
Bloch and Bloch, J. de phys. et rad. (6) **6**, 154 (1925). λ1465–λ1869, 178 lines. (C)

Mn I (X) I.P. 7.41(BG)
Mn II I.P. 15.56
Curtis, Phys. Rev. **53**, 474 (1938). λ953–λ1960, 432 lines class. (**A**)

Mn III I.P. 34.4*
Kruger and Gilroy, Phys. Rev. **48**, 720 (1935). λ892–λ895, 3 lines class. correction to Gilroy (1931). (**B**)
*Gilroy, Phys. Rev. **38**, 2217 (1931). λ915–λ1998, 64 lines class. (C)

Mn IV I.P. 52(B)
Bowen, Phys. Rev. **52**, 1153 (1937). λ540–λ1973, 156 lines class. (**A**)
White, Phys. Rev. **33**, 914 (1929). λ1742–λ1790, 12 lines class. (C)

Mn V I.P. 75.7*
Bowen, Phys. Rev. **47**, 924 (1935). λ382–λ458, 74 lines class. (**B**)
*White, Phys. Rev. **33**, 672 (1929). λ405–λ1621, 49 lines class. (C)

Mn VI
Cady, Phys. Rev. **43**, 322 (1933). λ307–λ330, 30 lines class. (**B**)

Mn VII I.P. 118.677
Kruger and Weissberg, Phys. Rev. **52**, 314 (1937). λ111–λ468, 21 lines class. (**A**)

Mn VIII I.P. 195.5
Kruger, Weissberg and Phillips, Phys. Rev. **51**, 1090 (1937). λ122, λ125, 2 lines class. (**B**)
Kruger and Weissberg, Phys. Rev. **48**, 659 (1935). λ122, λ125, 2 lines class. provisional wave-lengths.

Mn IX I.P. 221
Edlén, Zeits. f. Physik **104**, 407 (1937). λ105–λ115, 9 lines class. (**B**)

Mn X I.P. 247.2
Edlén, Zeits. f. Physik **104**, 188 (1937). λ100–λ105, 11 lines class. (**B**)

Mn XIII
Edlén, Zeits. f. Physik **103**, 536 (1936). λ67, 2 lines class. (**B**)

Mn XIV I.P. (402)
Edlén, Zeits. f. Physik **103**, 536 (1937). λ57–λ80, 13 lines class. (**A**)

Mn XV I.P. 433.14
Edlén, Zeits. f. Physik **100**, 621 (1936). λ45–λ75, 12 lines class. (**A**)

Mn XVI I.P. 1130.5
Tyrén, Zeits. f. Physik **111**, 314 (1938). λ13–λ19, 9 lines class. (**A**)

Absorption
Paul, Phys. Rev. **52**, 923 (1937). λ1085–λ1923, 57 lines.

Iron 26

Fe general
Bloch and Bloch, Comptes rendus **197**, 679 (1933). λ365–λ1149, 171 lines. (**B**)
Bloch and Bloch, J. de phys. et rad. (6) **6**, 105 (1925). λ1505–λ1896, 286 lines. (C)
Bloch and Bloch, Ann. de physique (10) **6**, 409 (1926). λ1877–λ2000, 279 lines, assigned as below. (C)

Fe I I.P. 7.83(BG)
Green, Phys. Rev. **55**, 1209 (1939). λ1934–λ1974, 29 lines. (**B**)
Bloch and Bloch, Ann. de physique (10) **6**, 409 (1926). λ1934–λ1999, 44 lines. (C)

Fe II I.P. 16.16(M)
Green, Phys. Rev. **55**, 1209 (1939). λ897–λ2000, 273 lines class. (**B**)
Bloch and Bloch, Ann. de physique (10) **6**, 409 (1926). λ1877–λ1999, 22 lines. (C)
Dobbie, Proc. Roy. Soc. **A151**, 703 (1935), *Annals of the Solar Physics Observatory* (Cambridge), Vol. 5, Part I (1938). Terms.
Edlén is understood to have considerable unpublished material on Fe II.

Fe III I.P. 30.48*
Bowen, Phys. Rev. **52**, 1153 (1937). λ1123–λ1926, 12 lines class. (**B**)
Green, Phys. Rev. **55**, 1209 (1939). λ860–λ2000, 22 lines class. (**B**)
Green, unpublished 1939. λ1550–λ1997, 202 lines. (**B**)

Iron 26 (*continued*)

Bloch and Bloch, Ann. de physique (10) **6**, 409 (1926). λ1877–λ2000, 213 lines. (C)

*Edlén, unpublished 1939 (see Astrophys. J. **90**, 378 (1939). λ727–λ2000, 500 lines class. (A)

Fe IV I.P. 56.8*

Kruger and Gilroy, Phys. Rev. **48**, 720 (1935). λ526–λ527, 3 lines class. corrections to Gilroy (1931). (B)

*Gilroy, Phys. Rev. **38**, 2217 (1931). λ575–λ1826, 70 lines class. (C)

Fe V

Bowen, Phys. Rev. **52**, 1153 (1937). λ364–λ1554, 145 lines class. (A)

White, Phys. Rev. **33**, 914 (1929). λ1431–λ1469, 9 lines class. (C)

Fe VI

Bowen, Phys. Rev. **47**, 924 (1935). λ276–λ319, 101 lines class. (A)

Fe VII

Cady, Phys. Rev. **43**, 322 (1933). λ231–λ246, 33 lines class. (B)

Bowen and Edlén, Nature **143**, 374 (1939). Terms only, wave-lengths unpublished, alters Cady's analysis.

Fe VIII I.P. 150.427

Kruger and Weissberg, Phys. Rev. **52**, 314 (1937). λ93–λ371, 15 lines class. (A)

Fe IX I.P. 233.5

Kruger, Weissberg and Phillips, Phys. Rev. **51**, 1090 (1937). λ103, λ106, 2 lines class. (B)

Fe X I.P. 261

Edlén, Zeits. f. Physik **104**, 407 (1937). λ94–λ98, 8 lines class. (B)

Fe XI I.P. 288.9

Edlén, Zeits. f. Physik **104**, 188 (1937). λ86–λ91, 12 lines class. (B)

Fe XIV

Edlén, Zeits. f. Physik **103**, 536 (1936). λ59, λ60—2 lines class. (B)

Fe XV I.P. (454)

Edlén, Zeits. f. Physik **103**, 536 (1936). λ50–λ71, 12 lines class. (A)

Fe XVI I.P. 487.01

Edlén, Zeits. f. Physik **100**, 621 (1936). λ39–λ97, 13 lines class. (A)

Fe XVII I.P. 1259.7

Tyrén, Zeits. f. Physik **111**, 314 (1938). λ12–λ17, 9 lines class. (A)

Cobalt 27

Co general

Bloch and Bloch, J. de phys. et rad. (6) **6**, 105 (1925). λ1425–λ1882, 342 lines. (C)

Moore, unpublished 1939, λ1836–λ2000, Co I, II, III?

Co I I.P. 7.84

Russell, King and Moore. Phys. Rev. **58**, 407 (1940). λ1814–λ2000, 144 lines, 79 class. (C)

Co II I.P. 16.9(M)

Findlay, Phys. Rev. **36**, 5 (1930). λ1941–λ1998, 6 lines class. (B)

Co V I.P. 83.1*

Kruger and Gilroy, Phys. Rev. **48**, 720 (1935). λ356, 3 lines class. corrections to Gilroy (1931). (B)

*Gilroy, Phys. Rev. **38**, 2217 (1931). λ413–λ1489, 57 lines class. (C)

Co VI

Bowen, Phys. Rev. **53**, 889 (1938). λ266–λ307, 103 lines class. (B)

Phillips and Kruger, Phys. Rev. **54**, 839 (1938). Suggested alternative classification.

Co VIII

Cady, Phys. Rev. **43**, 322 (1933). λ181–λ193, 27 lines class. See revision of Fe VII (Bowen and Edlén). (B)

Co XI I.P. 304

Edlén, Zeits. f. Physik **104**, 407 (1937). λ81–λ85, 6 lines class. (B)

Co XV

Edlén, Zeits. f. Physik **103**, 536 (1936). λ53, 2 lines class. (B)

Co XVI I.P. (510)

Edlén, Zeits. f. Physik **103**, 536 (1936). λ47–λ62, 9 lines class. (A)

Co XVII I.P. 544.08

Edlén, Zeits. f. Physik **100**, 621 (1936). λ41–λ59, 10 lines class. (A)

Co XVIII I.P. 1396

Tyrén, Zeits. f. Physik **111**, 314 (1938). λ12–λ15, 7 lines class. (A)

Nickel 28

Ni general

Bloch and Bloch, J. de phys. et rad. (6) **6**, 105 (1925). λ1370–λ1859, 330 lines spark. (C)

Ni I I.P. 7.606

Russell, Phys. Rev. **34**, 821 (1929). λ1964–λ2000, 7 lines class. (C)

Nickel 28 (*continued*)

Ni II I.P. 18.4(M)

Shenstone, Phys. Rev. **30**, 255 (1927). λ1812–λ1996, 8 lines class. **(C)**

Lang, Phys. Rev. **31**, 773 (1928). λ1703–λ1952, 13 lines class. **(C)**

Lang, Phys. Rev. **33**, 547 (1929). λ1253–λ1537, 26 lines class. **(C)**

Menzies, Proc. Roy. Soc. **A122**, 134 (1929). λ1164–λ1965, 111 lines class. **(C)**

Yamanouchi, Proc. Phys. Math. Soc. Japan **20**, 242 (1938). Terms (journal not available).

Ni VI

Gilroy, Phys. Rev. **38**, 2217 (1931). λ844–λ1192, 25 lines class. **(C)**

Kruger and Gilroy, Phys. Rev. **48**, 720 (1935). λ260–λ261, 3 lines class. **(B)**

Ni VII

Phillips and Kruger, Phys. Rev. **54**, 839 (1938). λ205–λ229, 92 lines class. **(B)**

Ni IX

Cady, Phys. Rev. **43**, 322 (1933). λ146–λ155, 20 lines class. See revision of Fe VII (Bowen and Edlén). **(B)**

Ni XVIII I.P. 604.1

Edlén, Zeits. f. Physik **100**, 621 (1936). λ44–λ53, 4 lines class. **(B)**

Copper 29

Cu general

Bloch, Bloch and Farineau, J. de phys. et rad. (7) **3**, 437 (1932). λ386–λ1377, 427 lines. **(B)**

Bloch and Bloch, Comptes rendus **197**, 132 (1933). λ240–λ383, 86 lines. **(B)**

Kruger, Phys. Rev. **44**, 826 (1933). λ109–λ476, 440 lines, probably Cu VI–IX. **(B)**

Bloch and Bloch, J. de phys. et rad. (6) **6**, 154 (1925). λ1359–λ1931, 177 lines. **(C)**

Selwyn, Proc. Phys. Soc. **41**, 392 (1929). λ1685–λ1825, 13 lines. **(C)**

Cu I I.P. 7.68(BG)

Shenstone, Phys. Rev. **34**, 1623 (1929). Classifications from Selwyn's lines. **(C)**

Cu II I.P. 20.18

Shenstone, Phil. Trans. Roy. Soc. **A751**, 195 (1936). λ676–λ2000, 476 lines class. **(A)**

McLennan and Quinlan, Phil. Mag. (7) **14**, 823 (1932). λ1979, λ1990—2 lines. **(C)**

Cu III

Bloch and Bloch, Comptes rendus **200**, 2017 (1935). Classifications.

Cu VII

Kruger and Gilroy, Phys. Rev. **48**, 720 (1935). λ200–λ201, 3 lines class. **(B)**

Cu XIX

Edlén, Zeits. f. Physik **100**, 621 (1936). λ47, 2 lines class. **(B)**

Zinc 30

Zn general

Bloch and Bloch, Comptes rendus **201**, 137 (1935). λ425–λ479, 24 lines, included in Ann. de physique (1936). **(B)**

Bloch and Bloch, Ann. de physique (11) **5**, 325 (1936). λ227–λ1981, 490 lines, 155 assigned as below. **(B & C)**

Selwyn, Proc. Phys. Soc. **41**, 392 (1929). λ1671–λ1972, 11 lines. **(C)**

Zn I I.P. 9.36(BG)

Bloch and Bloch, Ann. de physique (11) **5**, 325 (1936). λ1590, 1 line. **(C)**

Hetzler, Boremann and Burns, Phys. Rev. **48**, 656 (1935). 2 calculated lines, λ1404, λ1458.

Zn II I.P. 17.89(BG)

Lang, Proc. Nat. Acad. Sci. **15**, 414 (1929). λ984–λ1930, 11 lines class. **(C)**

Takahashi, Ann. d. Physik (5) **3**, 27 (1929). λ834–λ1969, 46 lines, 30 class. **(C)**

Bloch and Bloch, Ann. de physique (11) **5**, 325 (1936). λ1361–λ1928, 4 lines. **(C)**

Zn III I.P. 39.5(KS)

Mazumder, Ind. J. Phys. **10**, 171 (1936). λ498–λ1975, 226 lines class. **(C)**

Bloch and Bloch, Ann. de physique (11) **5**, 325 (1936). λ678–λ1981, 54 lines. **(B & C)**

Zn IV

Bloch and Bloch, Ann. de physique (11) **5**, 325 (1936). λ467–λ1900, 107 lines, 32 class. **(B & C)**

Absorption

Beutler and Guggenheimer, Zeits. f. Physik **87**, 176 (1933). λ714–λ1109, 24 lines class.

Gallium 31

Ga general

Lang, Phys. Rev. **30**, 762 (1927). λ1455–λ1538, 12 lines. **(C)**

Ga I (L) I.P. 5.97(BG)
Ga II I.P. 20.43

Sawyer and Lang, Phys. Rev. **34**, 712 (1929). λ829–λ1846, 38 lines class. **(C)**

Ga III I.P. 30.6(BG)

Lang, Phys. Rev. **30**, 762 (1927). λ632–λ1535, 9 lines class. **(C)**

Gallium 31 (*continued*)

Ga IV I.P. 63.8(KS)

Mack, Laporte and Lang, Phys. Rev. **31**, 748 (1928). λ422–λ1466, 39 lines class. (C)

Germanium 32

Ge I I.P. 7.89(M)

Gartlein, Phys. Rev. **31**, 782 (1928). λ1874–λ2000, 27 lines, 21 class. (C)

K. R. Rao, Proc. Roy. Soc. **A124**, 465 (1929). λ1639–λ1999, 77 lines, 64 class. (C)

Ge II I.P. 16(M)

Lang, Phys. Rev. **34**, 697 (1929). λ999–λ1649, 18 lines class. (C)

Ge III I.P. 34.07

Lang, Phys. Rev. **34**, 697 (1929). λ543–λ1978, 48 lines class. (C)

Ge IV I.P. 45.5(BG)

Lang, Phys. Rev. **34**, 697 (1929). λ440–λ1648, 19 lines class. (C)

Ge V I.P. 93.0

Kruger and Shoupp, Phys. Rev. **46**, 124 (1934). λ295–λ305, 3 lines class. (**B**)

Mack, Laporte and Lang, Phys. Rev. **31**, 748 (1928). λ943–λ1222, 33 lines class. (C)

Arsenic 33

As general

Queney, J. de phys. et rad. (6) **10**, 448 (1929). λ711–λ2000, 238 lines, 16 class. As IV, V. (C)

As I I.P. 10.5

A. S. Rao, Proc. Phys. Soc. **44**, 594 (1932). λ1313–λ1945, 161 lines, 126 class. (C)

As II I.P. 20.1*

A. S. Rao, Proc. Phys. Soc. **44**, 343 (1932). λ932–λ1769, 46 lines class. included in Ind. J. Phys. (1933). (C)

*A. S. Rao, Ind. J. Phys. **7**, 561 (1933). λ803–λ1769, 68 lines class. (C)

As III I.P. 28.0(BG)

K. R. Rao, Proc. Phys. Soc. **43**, 68 (1931). λ604–λ1274, 19 lines class. (**B**)

Pattabhiramiah and A. S. Rao, Ind. J. Phys. **3**, 437 (1929). λ866–λ1750, 12 lines class. (C)

As IV I.P. 49.9

K. R. Rao, Proc. Roy. Soc. **A134**, 604 (1932). λ530–λ1481, 45 lines class. (**B & C**)

Queney, J. de phys. et rad. (6) **10**, 448 (1929). λ742–λ981, 12 lines class. (C)

As V I.P. 62.5(BG)

Queney, J. de phys. et rad. (6) **10**, 448 (1929). λ715–λ1030, 4 lines class. (C)

Sawyer and Humphreys, Phys. Rev. **32**, 583 (1928). λ601–λ1057, 9 lines class. (C)

As VI I.P. 126.9

Kruger and Shoupp, Phys. Rev. **46**, 124 (1934). λ219–λ233, 4 lines class. (**B**)

Pattabhiramiah and A. S. Rao, Zeits. f. Physik **53**, 587 (1929). λ812–λ1016, 29 lines class. (C)

Selenium 34

Se general

K. R. Rao and Murti, Proc. Roy. Soc. **A145**, 694 (1934). λ561–λ861, 44 lines. (**B**)

Goudet, J. de phys. et rad. (7) **6**, 433 (1935). λ332–λ1294, 500 lines, 238 assigned as below. (**B**)

Lacroute, J. de phys. et rad. (6) **9**, 180 (1928). λ1234–λ1994, 68 lines. (C)

Se I I.P. 9.70*

Ruedy and Gibbs, Phys. Rev. **46**, 880 (1934). λ1314–λ1995, 135 lines, 108 class. (A)

K. R. Rao and Murti, Proc. Roy. Soc. **A145**, 694 (1934). λ1413–λ1995, 47 lines, 27 class. (**B**)

*Gibbs and Ruedy, Phys. Rev. **40**, 204 (1932). λ1607–λ1961, 10 lines provisional wave-lengths included in Ruedy and Gibbs, Phys. Rev. 1934.

Se II I.P. 21.3, 21.6*

Martin, Phys. Rev. **48**, 938 (1935). λ695–λ1667, 127 lines class. (A)

*Krishnamurty and K. R. Rao, Proc. Roy. Soc. **A149**, 56 (1935). λ746–λ1667, 50 lines class. (**B**)

Goudet, J. de phys. et rad. (7) **6**, 433 (1935). λ746–λ1294, 38 lines. (**B**)

Bloch and Bloch, J. de phys. et rad. (7) **6**, 441 (1935). Classifications.

Se III I.P. 33.93*

Badami and K. R. Rao, Proc. Roy. Soc. **A140**, 387 (1933). λ685–λ1126, 56 lines class. (**B**)

*K. R. Rao and Murti, Proc. Roy. Soc. **A145**, 681 (1934). λ518–λ1993, 88 lines, 30 class. (**B**)

Goudet, J. de phys. et rad. (7) **6**, 433 (1935). λ518–λ1207, 113 lines. (**B**)

Bloch and Bloch, J. de phys. et rad. (7) **6**, 441 (1935). Classifications.

Se IV I.P. 47.72

K. R. Rao and Badami, Proc. Roy. Soc. **A131**, 154 (1931). λ636–λ1967, 24 lines class. (**B**)

Goudet, J. de phys. et rad. (7) **6**, 433 (1935). λ636–λ1167, 18 lines. (**B**)

Selenium 34 (*continued*)

Se V I.P. 72.8

K. R. Rao and Badami, Proc. Roy. Soc. **A131**, 154 (1931). λ506–λ1150, 22 lines class. **(B & C)**

K. R. Rao and Murti, Proc. Roy. Soc. **A145**, 694 (1934). λ675, 1 line class. **(B)**

Goudet, J. de phys. et rad. (7) **6**, 433 (1935). λ506–λ1228, 20 lines. **(B)**

Se VI I.P. 81.4*

Goudet, J. de phys. et rad. (7) **6**, 433 (1935). λ453–λ887, 7 lines. **(B)**

*Sawyer and Humphreys, Phys. Rev. **32**, 583 (1928). λ453–λ887, 7 lines class. **(C)**

Se VII I.P. 165.5*

K. R. Rao and Murti, Proc. Roy. Soc. **A145**, 694 (1934). λ760–λ819, 4 lines class. **(B)**

*Kruger and Shoupp, Phys. Rev. **46**, 124 (1934). λ171–λ181, 4 lines class. **(B)**

Goudet, J. de phys. et rad. (7) **6**, 433 (1935). λ561–λ861, 42 lines. **(B)**

Bromine 35

Br general

Vaudet, Comptes rendus **185**, 1270 (1927). λ1302–λ1943, 101 lines. **(C)**

Lacroute, Ann. de physique (11) **3**, 5 (1935). λ646–λ1994, 135 lines, 122 assigned as below. **(C)**

Br I I.P. 11.80(BG), 12.2*

Lacroute, Ann. de physique (11) **3**, 5 (1935). λ1385–λ1730, 23 lines. **(C)**

*de Bruin and Kiess, Science **69**, 360 (1929). Classifications.

Br II I.P. 19.1(B)

Lacroute, Ann. de physique (11) **3**, 5 (1935). λ851–λ1981, 50 lines. **(C)**

Bloch, Bloch and Lacroute, Comptes rendus **199**, 41 (1934). Terms.

Br III I.P. 35.7

K. R. Rao and Krishnamurti, Proc. Roy. Soc. A161, 38 (1937). λ666–λ818, 15 lines class. **(B)**

Lacroute, Ann. de physique (11) **3**, 5 (1935). λ649–λ1994, 49 lines. **(C)**

Br IV I.P. 50

A. S. Rao and Krishnamurti, Proc. Phys. Soc. **46**, 531 (1934). λ538–λ736, 39 lines class. **(B)**

Br V

A. S. Rao and K. R. Rao, Proc. Phys. Soc. **46**, 163 (1934). λ482–λ856, 12 lines class. **(B)**

Br VI

A. S. Rao and K. R. Rao, Proc. Phys. Soc. **46**, 163 (1934). λ499–λ940, 14 lines class. **(B)**

Br VII

A. S. Rao and K. R. Rao, Proc. Phys. Soc. **46**, 163 (1934). λ502–λ780, 35 lines class. **(B)**

Br VIII I.P. 208.8

Kruger and Shoupp, Phys. Rev. **46**, 124 (1934). λ138, λ140, 2 lines class. **(B)**

Krypton 36

Kr I I.P. 13.94

Boyce, Phys. Rev. **47**, 718 (1935). λ945–λ1235, 10 lines class. **(A)**

Kr II I.P. 24.47

Boyce, Phys. Rev. **47**, 718 (1935). λ554–λ964, 82 lines class. **(A)**

Kr III I.P. 36.8

Boyce, Phys. Rev. **47**, 718 (1935). λ516–λ1923, 138 lines class. **(A)**

Kr IV

Boyce, Phys. Rev. **47**, 718 (1935). λ805–λ842, 3 lines class. **(B)**

Absorption

Beutler, Zeits. f. Physik **93**, 177 (1935). λ850–λ1003, 29 lines class.

Rubidium 37

Rb general

Ricard and Valancogne, Comptes rendus **207**, 1093 (1938). λ1046–λ2000, 92 lines. **(C)**

Rb I (L) I.P. 4.16(BG)
Rb II I.P. 27.3

Laporte, Miller and Sawyer, Phys. Rev. **38**, 843 (1931) λ697–λ741, 3 lines class. **(C)**

Rb III

Tomboulian, Phys. Rev. **54**, 350 (1938). λ482–λ815, 30 lines class. **(B)**

Absorption

Beutler, Zeits. f. Physik **91**, 131 (1934). λ595–λ810, 39 lines class.

Strontium 38

Sr I (L) I.P. 5.67(BG)

Sr II I.P. 10.98(BG)

Saunders, Schneider and Buckingham, Proc. Nat. Acad. Sci. **30**, 291 (1934). λ1483–λ1996, 18 lines class. **(A)**

Sr IV

Tomboulian, Phys. Rev. **54**, 350 (1938). λ358–λ710, 29 lines class. **(B)**

Yttrium 39

Y general

McLennan and Liggett, Trans. Roy. Soc. Canada **20**, 372 (1926). λ1788, 1 line. (**C**)

Y I (X) I.P. 6.5(BG)
Y II (X) I.P. 12.3(BG)

Russell and Meggers, Bur. Stand. J. Research **2**, 733 (1929). Terms.

Y III I.P. 20.4(BG)

Bowen and Millikan, Phys. Rev. **28**, 923 (1926). λ989, λ996—2 lines class. (**C**)

Russell and Meggers, Bur. Stand. J. Research **2**, 733 (1929). Terms.

Y V I.P. 76.5

Paul and Rense, Phys. Rev. **56**, 1110 (1939). λ314–λ629, 41 lines class. (**B**)

Zirconium 40

Zr I (X) I.P. 6.92(BG)
Zr II I.P. 13.97

Kiess and Kiess, Bur. Stand. J. Research **5**, 1205 (1930). λ1744–λ1999, 21 lines class. (**A**)

Zr III I.P. 24.00

Kiess and Lang, Bur. Stand. J. Research **5**, 305 (1930). λ756–λ1990, 61 lines class. (**A**)

Zr IV I.P. 33.83

Kiess and Lang, Bur. Stand. J. Research **5**, 305 (1930). λ629–λ1608, 12 lines class. (**B**)

Zr VI I.P. 98.4

Paul and Rense, Phys. Rev. **56**, 1110 (1939). λ236–λ568, 46 lines class. (**B**)

Columbium 41

Cb general

McLennan and Liggett, Trans. Roy. Soc. Canada **20**, 377 (1926). λ1590–λ1983, 71 lines. (**C**)

Cb I (O)

Cb III I.P. 24.2(B)

Eliason, Phys. Rev. **43**, 745 (1933). λ1423–λ1600, 26 lines class. (**B**)

Cb IV I.P. 38.1

Lang, Zeeman Verh. (The Hague, 1935), p. 44. λ542–λ1978, 95 lines class. (**A**)

Cb V I.P. 49.3(B)

Trawick, Phys. Rev. **46**, 63 (1934). λ465–λ1877, 12 lines class. (**B**)

Molybdenum 42

MO I (X) I.P. 7.35(BG)
MO IV

Eliason, Phys. Rev. **43**, 745 (1933). λ856–λ1995, 41 lines class. (**B**)

MO V

Trawick, Phys. Rev. **48**, 223 (1935). λ410–λ1849, 91 lines class. (**A**)

MO VI

Trawick, Phys. Rev. **46**, 63 (1934). λ373–λ1576, 12 lines class. (**B**)

Ruthenium 44 (O)

Ru I (X) I.P. 7.7(M)

Rhodium 45 (O)

Rh I (X) I.P. 7.7(BG)

Palladium 46

Pd I I.P. 8.3(BG)

Shenstone, Phys. Rev. **36**, 669 (1930). λ1946–λ1993, 9 lines, 7 class. (**C**)

Pd II I.P. 19.8

Shenstone, Phys. Rev. **32**, 30 (1928). λ1212–λ2000, 53 lines class. (**C**)

Silver 47

Ag general

Bloch, Bloch and Farineau, J. de phys. et rad. (7) **3**, 437 (1932). λ260–λ1321, 727 lines. (**B & C**)

Bloch and Bloch, J. de phys. et rad. (6) **6**, 157 (1925). λ1389–λ1890, 298 lines. (**C**)

Selwyn, Proc. Phys. Soc. **41**, 392 (1929). λ1709–λ1995, 3 lines. (**C**)

Ag I I.P. 7.54(BG)

Shenstone, Phys. Rev. **57**, 894 (1940). λ1507–λ1850, 14 lines class. (**A**)

Ag II I.P. 21.9(BG), 21.4*

Shenstone, Phys. Rev. **31**, 317 (1928). λ1933, λ1994—2 lines class. (**C**)

Menzies, Proc. Roy. Soc. **A122**, 134 (1929). λ1107–λ1196, 3 lines class. (**C**)

*Gilbert, Phys. Rev. **47**, 847 (1935). λ729–λ1999, 111 lines class. (**C**)

Ag III I.P. 39.5

Gilbert, Phys. Rev. **48**, 338 (1935). λ710–λ2000, 193 lines class. (**C**)

Absorption

Paul, Phys. Rev. **52**, 923 (1937). λ1032–λ1893, 21 lines.

Cadmium 48

Cd general

Bloch and Bloch, Comptes rendus **201**, 137 (1935). λ493–λ547, 20 lines, included in Ann. de physique. 1936. **(B)**

Bloch and Bloch, Ann. de physique (11) **5**, 325 (1936). λ212–λ1996, 906 lines, 125 assigned as below. **(B & C)**

Selwyn, Proc. Phys. Soc. **41**, 392 (1929). λ1669–λ1820, 3 lines. **(C)**

Cd I (O) I.P. 8.96 (BG)

Cd II I.P. 16.84

Takahashi, Ann. d. Physik (5) **3**, 27 (1929). λ711–λ1995, 96 lines—51 class. **(C)**

Cd III I.P. 38.0(KS)

Bloch and Bloch, Ann. de physique (11) **5**, 325 (1936). λ677–λ1944, 33 lines. **(B & C)**

Gibbs and White, Phys. Rev. **31**, 776 (1928). λ677–λ1943, 35 lines class. **(C)**

McLennan, McLay and Crawford, Trans. Roy. Soc. Canada **22**, 45 (1928). λ1470–λ1943, 31 lines class. **(C)**

Cd IV

Bloch and Bloch, Ann. de physique (11) **5**, 325 (1936). λ495–λ1930, 124 lines—32 class. **(B & C)**

Absorption

Beutler, Zeits. f. Physik **87**, 19 (1933). λ683–λ1023, 27 lines.

Indium 49

In I (L) I.P. 5.76(BG)

In II I.P. 18.79

Lang and Sawyer, Zeits. f. Physik **71**, 453 (1931). λ681–λ1977, 76 lines class. **(A)**

In III I.P. 27.9(BG)

Lang, Proc. Nat. Acad. Sci. **13**, 341 (1927). λ686–λ1749, 11 lines class. **(C)**

Lang, Proc. Nat. Acad. Sci. **15**, 414 (1929). λ882–λ1744, 5 lines class. **(C)**

In IV I.P. 57.8(KS)

Gibbs and White, Phys. Rev. **31**, 776 (1928). λ472–λ1726, 36 lines class. **(C)**

Tin 50

Sn I I.P. 7.297

Meggers, J. Research Nat. Bur. Stand. **24**, 153 (1940). λ1697–λ2000, 80 lines, 56 class. **(A)**

Sn II I.P. 14.56

McCarwik and Sawyer, Phys. Rev. **54**, 71 (1938). λ888–λ1900, 32 lines class. **(A)**

Sn III I.P. 30.5(BG), 30

Green and Loring, Phys. Rev. **30**, 575 (1927). λ1161–λ1818, 9 lines class. **(C)**

Gibbs and Vieweg, Phys. Rev. **34**, 400 (1929), λ744–λ1992, 35 lines class. **(C)**

Sn IV I.P. 39.4(BG)

Lang, Proc. Nat. Acad. Sci. **13**, 341 (1927). λ956–λ1438, 9 lines class. **(C)**

Lang, Proc. Nat. Acad. Sci. **15**, 414 (1929). λ500–λ710, 8 lines class. **(C)**

Sn V I.P. 80.7(KS)

Gibbs and White, Proc. Nat. Acad. Sci. **14**, 345 (1928). λ356–λ1535, 34 lines class. **(C)**

Antimony 51

Sb general

Bloch and Bloch, J. de phys. et rad. (7) **8**, 217 (1937). λ263–λ1997, 488 lines, 188 assigned as below. **(B & C)**

Sb I I.P. 8.35

Bloch and Bloch, J. de phys. et rad. (7) **8**, 217 (1937). λ1699–λ1971, 6 lines. **(C)**

Sb II I.P. 18

Lang and Vestine, Phys. Rev. **42**, 233 (1932). λ691–λ1991, 99 lines, 60 class. **(B)**

Krishnamurty, Ind. J. Phys. **10**, 83 (1936). λ876–λ1875, 20 lines class. **(C)**

Bloch and Bloch, J. de phys. et rad. (7) **8**, 217 (1937). λ900–λ1991, 87 lines. **(C)**

Sb III I.P. 24.7*

Bloch and Bloch, J. de phys. et rad. (7) **8**, 217 (1937). λ691–λ1946, 37 lines. **(B & C)**

Pattabhiramiah and A. S. Rao, Ind. J. Phys. **3**, 437 (1929). λ1814, λ1840—2 lines class. **(C)**

*Lang, Phys. Rev. **35**, 445 (1930). λ691–λ1947, 35 lines class. **(C)**

Sb IV I.P. 44 (BG), 42*

Bloch and Bloch, J. de phys. et rad. (7) **8**, 217 (1937). λ517–λ1915, 45 lines. **(B & C)**.

*Green and Lang, Proc. Nat. Acad. Sci. **14**, 706 (1928). λ805–λ1514, 19 lines class. **(C)**

Gibbs and Vieweg, Phys. Rev. **34**, 400 (1929). λ456–λ1667, 35 lines class. **(C)**

Badami, Proc. Phys. Soc. **43**, 538 (1931). λ1358–λ1915, 5 lines class. **(C)**

Sb V I.P. 55.5(BG)

Bloch and Bloch, J. de phys. et rad. (7) **8**, 217 (1937). λ831–λ1906, 13 lines. **(B & C)**

Lang, Proc. Nat. Acad. Sci. **13**, 341 (1927). λ746–λ1525, 9 lines class. **(C)**

Badami, Proc. Phys. Soc. **43**, 538 (1931). Terms.

Sb VI I.P. 107.1

Kruger and Shoupp, Phys. Rev. **46**, 124 (1934). λ279–λ293, 4 lines class. **(B)**

Bloch and Bloch, J. de phys. et rad. (7) **8**, 217 (1937); Comptes rendus **204**, 424 (1937). λ280–λ1338, 30 lines class. **(B & C)**

Schoepfle, Phys. Rev. **43**, 742 (1933). λ883–λ1332, 31 lines class. **(C)**

Tellurium 52

Te general

Bloch and Bloch, J. de phys. et rad. (7) **6**, 441 (1935). λ157–λ1312, 521 lines, 87 assigned as below. **(B)**

Lacroute, J. de phys. et rad. (6) **9**, 180 (1928). λ1256–λ1998, 93 lines. **(C)**

Bloch and Bloch, Comptes rendus **208**, 336 (1939). λ110–λ232, 108 lines. **(B)**

Te I I.P. 8.96(M)

Krishnamurty, Ind. J. Phys. **10**, 365 (1936). λ1555–λ1995, 24 lines—22 class. **(C)**

Bartelt, Zeits. f. Physik **88**, 522 (1934). Classifications.

Te III I.P. 30.5*

Bloch and Bloch, J. de phys. et rad. (7) **6**, 441 (1935). λ840–λ1145, 34 lines. **(B)**

*Krishnamurty, Proc. Roy. Soc. **A151**, 178 (1935). λ839–λ1145, 37 lines class. **(B)**

Krishnamurty, and K. R. Rao, Proc. Roy. Soc. **A158**, 562 (1937). λ612–λ1805, 27 lines class. **(B)**

Te IV I.P. 37.7

K. R. Rao, Proc. Roy. Soc. **A133**, 220 (1931). λ749–λ1459, 17 lines class. **(B)**

Bloch and Bloch, J. de phys. et rad. (7) **6**, 441 (1935). λ749–λ1197, 15 lines. **(B)**

Te V I.P. 60.0(BG)

Bloch and Bloch, J. de phys. et rad. (7) **6**, 441 (1935). λ359–λ1282, 24 lines—5 class. **(B)**

Gibbs and Vieweg, Phys. Rev. **34**, 400 (1929). λ603–λ1550, 23 lines class. **(C)**

Te VI I.P. 72.0

K. R. Rao, Proc. Roy. Soc. **A133**, 220 (1931). λ540–λ1314, 10 lines class. **(B)**

Bloch and Bloch, J. de phys. et rad. (7) **6**, 441 (1935). λ242–λ1071, 13 lines—6 class. **(B)**

Lang, Proc. Nat. Acad. Sci. **13**, 341 (1927). λ954, λ1078, 2 lines class. **(C)**

Te VII I.P. 136.5

Kruger and Shoupp, Phys. Rev. **46**, 124 (1934). λ227–λ244, 6 lines class. **(B)**

Bloch and Bloch, J. de phys. et rad. (7) **6**, 411 (1935). λ804–λ1123, 12 lines. **(B)**

Bloch and Bloch, J. de phys. et rad. (7) **8**, 217 (1937); Comptes rendus **204**, 424 (1937). λ228–λ1189, 24 lines class. **(B)**

Schoepfle, Phys. Rev. **43**, 742 (1933). λ784–λ1124, 24 lines class. **(C)**

Iodine 53

I general

Bloch, Bloch and Felici, J. de phys. et rad. (7) **8**, 355 (1937). λ190–λ1010—438 lines, 290 assigned as below. **(B)**

McLeod, Phys. Rev. **49**, 804 (1936). λ809–λ1876, 223 lines. **(B & C)**

Lacroute, Ann. de physique (11) **3**, 5 (1935). λ766–λ1999, 406 lines, 265 assigned as below. **(C)**

I I I.P. 10.2(M)

Lacroute, Ann. de physique (11) **3**, 5 (1935). λ1493–λ1876, 15 lines. **(C)**

Deb, Proc. Roy. Soc. **A139**, 380 (1933). Classifications.

I II I.P. 19.4*

Bloch, Bloch and Felici, J. de phys. et rad. (7) **8**, 355 (1937). λ480–λ995, 139 lines—13 class. **(B)**

Kalia, Ind. J. Phys. **9**, 179 (1934). λ1275–λ1982, 105 lines. **(C)**

*Lacroute, Ann. de physique (11) **3**, 5 (1935). λ766–λ1999, 148 lines—42 class. **(C)**

Murakawa, Zeits. f. Physik **109**, 162 (1938). Classifications.

I III

Bloch, Bloch and Felici, J. de phys. et rad. (7) **8**, 355 (1937). λ436–λ1004, 93 lines. **(B)**

Lacroute, Ann. de physique (11) **3**, 5 (1935). λ767–λ1999, 102 lines. **(C)**

I IV and higher

Bloch, Bloch and Felici, J. de phys. et rad. (7) **8**, 355 (1937). λ483–λ953, 45 lines. **(B)**

I VIII I.P. 169.1

Kruger and Shoupp, Phys. Rev. **46**, 124 (1934). λ190–λ202, 4 lines class. **(B)**

Bloch, Bloch and Felici, J. de phys. et rad. (7) **8**, 355 (1937). λ190, λ194—2 lines class. **(B)**

Absorption

McLeod, Phys. Rev. **45**, 802 (1934). λ1420–λ1830, 8 lines.

Xenon 54

Xe I I.P. 12.078

Boyce, Phys. Rev. **49**, 730 (1936). λ1192–λ1469, 4 lines class. **(A)**

Abbink and Dorgelo, Zeits. f. Physik **47**, 221 (1928). λ1027–λ1469, 15 lines. **(C)**

Xe II I.P. 21.1

Boyce, Phys. Rev. **49**, 730 (1936). λ740–λ1244, 20 lines class. **(B)** For revision and extension of analysis see: Humphreys, J. Research Nat. Bur. Stand. **22**, 19 (1939).

Déjardin, Ann. de physique (10) **13**, 82 (1930). λ1881–λ1997, 26 lines. **(C)**

Xe III I.P. 32.0

Boyce, Phys. Rev. **49**, 730 (1936). λ627–λ1978, 128 lines class. **(A)**

Xe IV

Déjardin, Ann. de physique (10) **13**, 82 (1930). λ1881–λ1999, 49 lines. **(C)**

Absorption

Beutler, Zeits. f. Physik **93**, 172 (1935). λ926–λ996, 18 lines class.

Caesium 55

Cs I (L) I.P. 3.87(BG)
Cs II I.P. 23.4

Laporte, Miller and Sawyer, Phys. Rev. **39**, 458 (1932). λ612–λ927, 8 lines class, included in Olthoff and Sawyer, Phys. Rev. **42**. **(C)**

Olthoff and Sawyer, Phys. Rev. **42**, 766 (1932). λ607–λ927, 9 lines class. **(C)**

Ricard, Givord and George, Comptes rendus **205**, 1229 (1937). λ1179–λ1501, 3 lines class. **(C)**

Cs III I.P. 35(B)

Fitzgerald and Sawyer, Phys. Rev. **46**, 576 (1934). λ530–λ878, 17 lines class. **(C)**

Absorption

Beutler and Guggenheimer, Zeits. f. Physik **88**, 25 (1934). λ640–λ1008, 128 lines.

Barium 56

Ba I (L) I.P. 5.19(BG)
Ba II I.P. 9.96(BG)

Saunders, Schneider and Buckingham, Proc. Nat. Acad. Sci. **20**, 291 (1934). λ1398–λ1986, 26 lines class. **(A)**

Ba III (O) I.P. 35.5(B)
Ba IV

Fitzgerald and Sawyer, Phys. Rev. **46**, 576 (1934). λ570–λ740, 13 lines class. **(C)**

Lanthanum 57

La general

McLennan and Liggett, Trans. Roy. Soc. Canada **20**, 377 (1926). λ1699–λ1858, 3 lines. **(C)**

La I (L) I.P. 5.59(RM)
La II (X) I.P. 11.38(RM)
La III I.P. 19.1(RM)

Lang, Can. J. Research **A13**, 1 (1935). λ1082–λ1462, 5 lines class. **(B)**

Lang, Can. J. Research **A14**, 43 (1936). Corrections to Can. J. Research (1935).

Cerium 58

Ce I (L) I.P. 6.5 (estimate)
Ce II (X) I.P. 12.3 (estimate)
Ce III I.P. 20

Russell, King and Lang, Phys. Rev. **52**, 456 (1937). λ1680–λ1987, 31 lines class. **(B)**

Ce IV I.P. 33.3

Lang, Can. J. Research **A13**, 1 (1935). λ900–λ1881, 11 lines class. **(B)**

Lang, Can. J. Research **A14**, 127 (1936). λ447–λ1937, 22 lines class. **(B)**

Lang, Phys. Rev. **49**, 552 (1936). λ742–λ1915, 4 lines class. included in Can. J. Research 14 (1936). **(B)**

Badami, Proc. Phys. Soc. **43**, 53 (1931). λ1836–λ1950, 2 lines class. **(C)**

Praseodymium 59

Pr general

McLennan and Liggett, Trans. Roy. Soc. Canada **20**, 377 (1926). λ1533–λ1961, 3 lines. **(C)**

Pr I (L) I.P. 5.7 (estimate)

Neodymium 60

Nd general

McLennan and Liggett, Trans. Roy. Soc. Canada **20**, 377 (1926). λ1626, 1 line. **(C)**

Nd I (L) 5.7 (estimate)

Samarium 62

Sm I (L) I.P. 5.64(M^+)

Europium 63

Eu I (L) I.P. 5.64(B)
Eu II (X) I.P. 11.4(M)

Gadolinium 64

Gd I (L) I.P. 6.6 (estimate)

Terbium 65

Tb I (L) I.P. 6.7 (estimate)

Dysprosium 66

Dy I (L) I.P. 6.8 (estimate)

Holmium 67 (O)

Erbium 68 (O)

Thulium 69 (O)

Ytterbium 70

Yb I (L) I.P. 6.23(M)
Yb II (X) I.P. 12.05(M)

Lutecium 71 (O)

Hafnium 72

Hf I (O) Hf II I.P. 14.8

Meggers and Scribner, Bur. Stand. J. Research **13**, 625 (1934). λ1623–λ1993, 20 lines class. **(B)**

Tantalum 73 (O)

Tungsten 74

W general

Bloch and Bloch, J. de phys. et rad. **6**, 105 (1925). λ1453–λ1878, 409 lines. **(C)**

Bayen, Comptes rendus **180**, 57 (1925). λ1873–λ1999, 75 lines. **(C)**

Tungsten 74 (*continued*)

W I (O) 8.1(M)

W II

Laun, J. Research Nat. Bur. Stand. **21**, 207 (1938). λ1961–λ2000, 4 lines class. **(B)**

Rhenium 75

Re I (O) I.P. 7.85(M)

Osmium 76

Os I (O) I.P. 8.7(M)

Iridium 77 (O)

Platinum 78

Pt general

Bloch and Bloch, J. de phys. et rad. **6**, 154 (1925). λ1330–λ1912, 461 lines. **(C)**

Pt I I.P. 8.9

Livingood, Phys. Rev. **34**, 185 (1929). λ1929–λ1996, 11 lines, 4 class. **(C)**

Pt II I.P. 18.47

Shenstone, Phil. Trans. Roy. Soc. **A237**, 453 (1938). λ976–λ1998, 352 lines class. **(A)**

Gold 79

Au general

Bloch and Bloch, J. de phys. et rad. **6**, 154 (1925). λ1342–λ1930, 386 lines. **(C)**

McLennan and Liggett, Trans. Roy. Soc. Canada **20**, 377 (1926). λ1553–λ1997, 100 lines. **(C)**

Selwyn, Proc. Phys. Soc. **41**, 392 (1929). λ1647–λ1992, 36 lines, 22 assigned as below. **(C)**

Bloch and Bloch and Farineau, J. de phys. et rad. (7) **3**, 437 (1932). λ296–λ1342, 510 lines. **(B & C)**

Au I I.P. 9.20*

Selwyn, Proc. Phys. Soc. **41**, 392 (1929). λ1647–λ1952, 7 lines class. **(C)**

*McLennan and McLay, Proc. Roy. Soc. **A134**, 35 (1931). λ1624, λ1587, 2 lines class. and classifications of published material. **(C)**

Au II I.P. 20.0(B)

McLennan and McLay, Trans. Roy. Soc. Canada **22**, 103 (1928). λ1398–λ1925, 31 lines class. **(C)**

Selwyn, Proc. Phys. Soc. **41**, 392 (1929). λ1674–λ1925, 15 lines class. **(C)**

Sawyer and Thomson, Phys. Rev. **38**, 2293 (1931). λ1167–λ1362, 3 lines class. **(C)**

B. V. R. Rao, Proc. Roy. Soc. **A142**, 118 (1933). Classifications.

Mack and Fromer, Phys. Rev. **48**, 357 (1935). Classifications.

Mercury 80

Hg general

Bloch and Bloch, Ann. de physique (11) **6**, 561 (1936). λ223–λ1728, 1397 lines, 294 assigned as below. **(B & C)**

Déjardin, Ann. de physique (10) **8**, 424 (1927). λ1860–λ2000, 69 lines, assigned as below. **(C)**

Subbaraya, J. Mysore University **7**, 100 (1934). Hg II, III (journal not available).

Hg I I.P. 10.38(BG)

Beutler, Zeits. f. Physik **84**, 289 (1933). λ1204–λ1435, 17 lines class. in emission and absorption. **(B)**

Selwyn, Proc. Phys. Soc. **41**, 392 (1929). λ1775–λ1849, 3 lines class. **(C)**

Hg II I.P. 18.672

Paschen, Preuss. Akad. Wiss. Berlin Ber. **32**, 536 (1928). λ893–λ1988, 50 lines, 27 class. **(B)**

Bloch and Bloch, Ann. de physique (11) **6**, 561 (1936). λ893–λ1728, 80 lines. **(B & C)**

Déjardin, Ann. de physique (10) **8**, 424 (1927). λ1860–λ2000, 46 lines. **(C)**

Naude, Ann. d. Physik (5) **3**, 1 (1929). λ938–λ1996, 55 lines, 31 class. **(C)**

McLennan, McLay and Crawford, Proc. Roy. Soc. **A134**, 41 (1931). λ1459–λ1981, 4 lines class. and classifications of published material. **(C)**

Venkatasachar and Subbaraya, Zeits. f. Physik **73**, 413 (1932). Classifications.

Subbaraya, Zeits. f. Physik **78**, 541 (1932). Classifications.

Hg III I.P. 34.05*

Mack and Fromer, Phys. Rev. **48**, 357 (1935). λ740–λ1415, 14 lines class. **(B)**

*Johns, Can. J. Research **A15**, 193 (1937). λ570–λ1982, 248 lines class. **(B)**

Bloch and Bloch, Ann. de physique (11) **6**, 561 (1936). λ788–λ1728, 146 lines. **(B & C)**

Déjardin, Ann. de physique (10) **8**, 424 (1927). λ1894–λ1995, 10 lines. **(C)**

Ricard, J. de phys. et rad. (7) **7**, 315 (1936). λ1231–λ1383, 5 lines class. **(C)**

Hg IV

Bloch and Bloch, Ann. de Physik (11) **6**, 561 (1936). λ997–λ1728, 68 lines. **(B & C)**

Déjardin, Ann. de physique (10) **8**, 424 (1927). λ1881–λ1998, 13 lines. **(C)**

Subbaraya, Proc. Ind. Acad. Sci. **A1**, 39 (1934). Classifications.

Absorption

Beutler, Zeits. f. Physik **84**, 289 (1933). λ1204–λ1435, 17 lines class.

Beutler, Zeits. f. Physik **86**, 710 (1933). λ745–λ1301, 40 lines class.

Thallium 81

Tl general

Mack, Phys. Rev. **34**, 17 (1929). λ869–λ1070, 86 lines. **(C)**

Bloch, Bloch and Walden, J. de phys. et rad. **10**, 49 (1939). λ200–λ1400 many lines, chiefly Tl IV and higher. **(B)**

Tl I (L) I.P. 6.07(BG)

Tl II I.P. 20.33*

Smith, Proc. Nat. Acad. Sci. **14**, 951 (1928). λ1221–λ1909, 20 lines class. **(C)**

*Ellis and Sawyer, Phys. Rev. **49**, 145 (1936). λ639–λ1909, 91 lines, 90 class. **(C)**

Tl III I.P. 29.7(BG)

McLennan, McLay and Crawford, Proc. Roy. Soc. **A125**, 50 (1929). λ1231–λ1661, 7 lines class. **(C)**

Pattabhiramaya and A. S. Rao, Ind. J. Phys. **5**, 407 (1930). Classifications.

Tl IV I.P. 50.5(B)

Mack, Phys. Rev. **34**, 17 (1929). λ1028–λ1964, 13 lines class. **(C)**

K. R. Rao, Proc. Phys. Soc. **41**, 361 (1929). Classifications.

Mack and Fromer, Phys. Rev. **48**, 357 (1935). Classifications.

Absorption

Beutler and Demeter, Zeits. f. Physik **91**, 202 (1934). λ1490, λ1610—2 lines class.

Beutler and Demeter, Zeits. f. Physik **91**, 218 (1934). λ651–λ891, 9 lines class.

Lead 82

Pb general

Arvidson, Ann. d. Physik (5) **12**, 787 (1932). λ251–λ1439, 1050 lines, 532 assigned as below. **(B)**

PB I I.P. 7.38(BG)

Gieseler and Grotrian, Zeits. f. Physik **39**, 377 (1926). λ1644–λ1972, 3 lines class. **(C)**

Pb II I.P. 14.96*

Arvidson, Ann. d. Physik (5) **12**, 787 (1932). λ1110–λ1434, 5 lines. **(B)**

*Earls and Sawyer, Phys. Rev. **47**, 115 (1935). λ840–λ1922, 50 lines class. **(C)**

Pb III I.P. 31.9(BG)

Arvidson, Ann. d. Physik (5) **12**, 787 (1932). λ515–λ1439, 45 lines. **(B)**

Smith, Phys. Rev. **34**, 393 (1929). λ709–λ1827, 32 lines class. **(C)**

Smith, Phys. Rev. **36**, 1 (1930). λ961–λ1712, 4 lines class. **(C)**

Pb IV I.P. 42.11,* 42.0†

Arvidson, Ann. d. Physik (5) **12**, 787 (1932). λ433–λ1435, 84 lines. **(B)**

*Crawford, McLay and Crooker, Proc. Roy. Soc. **A158**, 455 (1937). λ477–λ1982, 12 lines class. and classifications of published material. **(B)**

†Schoepfle, Phys. Rev. **47**, 232 (1935). λ1715–λ1959, 4 lines class. and classifications of published material. **(C)**

Pb V I.P. 69.40*

Arvidson, Ann. d. Physik (5) **12**, 787 (1932). λ254–λ1418, 219 lines. **(B)**

Mack and Fromer, Phys. Rev. **48**, 357 (1935). Classifications.

*Schoepfle, Phys. Rev. **50**, 538 (1936). Classifications.

Pb VI and higher

Arvidson, Ann. d. Physik (5) **12**, 787 (1932). λ252–λ1433, 179 lines. **(B)**

Absorption

Kremenevsky, C. R. Acad. Sci. U.S.S.R. **3**, 251 (1935). λ1350–λ2000.

Bismuth 83

Bi general

Arvidson, Ann. d. Physik (5) **12**, 787 (1932). λ176–λ1487, 928 lines, 366 assigned as below. **(B)**

Bi I I.P. 7.25(M)

Toshnival, Phil. Mag. (7) **4**, 774 (1927). λ1902–λ1990, 10 lines, 3 class. **(C)**

Bi II I.P. 16.6(B)

Zumstein, Phys. Rev. **38**, 2214 (1931). λ1777–λ1902, 5 lines class. **(B)**

Arvidson, Ann. d. Physik (5) **12**, 787 (1932). λ1021–λ1487, 18 lines. **(B)**

Crawford and McLay, Proc. Roy. Soc. **A143**, 540 (1934). λ1186–λ1990, 27 lines class. and classifications of published materials. **(C)**

Bi III I.P. 25(BG)

Arvidson, Ann. d. Physik (5) **12**, 787 (1932). λ590–λ1455, 32 lines. **(B)**

Crawford and McLay, Proc. Roy. Soc. **A143**, 540 (1934). λ1363–λ1989, 19 lines class. and classifications of published materials. **(C)**

Bi IV I.P. 45.1(B)

Arvidson, Ann. d. Physik (5) **12**, 787 (1932). λ353–λ1438, 112 lines, 23 class. **(B)**

McLay and Crawford, Phys. Rev. **44**, 986 (1933). λ1723–λ1925, 4 lines class. and classifications of published material. **(C)**

Bi V I.P. 55.7*

Arvidson, Ann. d. Physik (5) **12**, 787 (1932). λ234–λ1394, 103 lines. **(B)**

*Schoepfle, Phys. Rev. **47**, 232 (1935). Classifications.

Bismuth 83 (*continued*)

Bi VI I.P. 93.97*

Arvidson, Ann. d. Physik (5) **12**, 787 (1932). λ176–λ1287, 163 lines, 8 class. (**B**)

Mack and Fromer, Phys. Rev. **48**, 357 (1935). Classifications.

*Schoepfle, Phys. Rev. **50**, 538 (1936). Classifications.

Bi VII and higher.

Arvidson, Ann. d. Physik (5) **12**, 787 (1932). λ265–λ309, 38 lines. (**B**)

Polonium 84 (O)

Radon 86

Rn I (O) I.P. 10.69(BG)

Radium 88

Ra I (L) I.P. 5.25(B)
Ra II I.P. 10.10

Rasmussen, Zeits. f. Physik **86**, 24 (1933). λ1888–λ1976, 4 lines class. (**C**)

Actinium 89 (O)

Thorium 90

Th I (O)
Th IV I.P. 29.38

Lang. Can. J. Research **14**, 43 (1936). λ846–λ1959, 15 lines class. (**B**)

Protactinium 91 (O)

Uranium 92 (O)