Finally, Rank pointed out that one could also carry out the *inverse* of this process, *i.e.* calculate far infra-red bands from near infra-red bands. This has actually been done by Rank, Skorinko, Eastman and Wiggins (**18**) for the 010-000 band of HCN, thus obtaining very precise standards (to better than $\pm 0{\cdot}003\ cm^{-1}$) in the region $624-803\ cm^{-1}$.

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14*a*. SOUS-COMMISSION DES TABLES D'INTENSITES

Report of Meeting, 16 August 1961

PRESIDENT: M. J. Minnaert

SECRETARY: H. Zirin

Sub-Commission 14*a* will now become a working committee of Commission 14 and be called the Working Committee on "Transition Probabilities and Cross-sections."

There were no corrections to the *Draft Report*. The President noted that data on collision cross-sections appeared for the first time, and that these should be improved and extended in the future. He recommended that the membership of the committee should be increased to deal with this topic.

Dr Seaton pointed out that if the work of the committee is to be so enlarged, it involves a very large task. Cross-sections are much more difficult to compile and evaluate than f-values.

Professor Aller reviewed the current situation on f-values of astrophysical interest. He pointed out particular atoms whose lines satisfy the three conditions of: having astrophysical interest; being amenable to accurate experimental techniques; and being within the possible range of theory. Such atoms are C, N, O, Ne, and A. Some atoms, such as Ca, Fe, and Pb have reasonably good f-values, but many others which do not were noted. Professor Aller also pointed out the discrepancy between various methods of measurement of f-values such as shock tubes and molecular beams. [Professor Aller's paper is appended to this report.]

Professor Greenstein commented on the need for f-values of various ions of Fe for studies of cooler stars. In particular, f-values for weak lines are needed, because these lines are free of self-absorption.

The President asked if the committee should make up a list, perhaps using the revised multiplet tables, of lines for which new f-values were urgently needed. Professor Greenstein commented that the actual lists of lines in observed spectra should be used. In the discussion it was noted by Dr Branscomb that the physicists working in the field look to the committee to inform them which lines are important.

Dr Kessler of the National Bureau of Standards reported on the NBS programme of compendia of transition probabilities. A bibliography has been compiled on unpunched cards, and persons desiring a bibliography on any ion should write to: Atomic Physics Data Center, National Bureau of Standards, Washington 25, D.C.

Dr Branscomb addressed the committee on the programme of laboratory astrophysics at the National Bureau of Standards. A broad programme is underway at NBS to provide data on atomic properties, statistical processes, diagnostic methods, and theoretical interpretations for astrophysics, aeronomy and cosmophysics. The f-values are being measured by the use of stabilized arcs, shock tubes, and high-temperature plasmas. Photo-detachment cross-sections are being studied both theoretically and experimentally, and there is also theoretical work on photo-ionization. The well-known work on theoretical and laboratory measurements of collision cross-sections is being continued. Finally, Dr Branscomb gave the committee some examples of the bibliography being compiled by the Atomic Physics Data Center mentioned by Dr Kessler.

Dr Branscomb also pointed out the need for a review article on the present situation in astrophysical f-values in a journal accessible to physicists, such as the *Reviews of Modern Physics*. The President agreed to transmit this suggestion to the Organizing Committee.

Professor Allen discussed the use of the f-sum rule in transition probabilities. In cases with one or two electrons, one can obtain a good approximation. In general, it is best to use the quantity gf. With the f-sum rule, one can at least rule out grossly inaccurate f-values.

Dr Naqvi spoke on the continuation at Harvard of the work of Dr Layzer (reported on in volume X of the *Transactions*) on calculation of f-values by means of screening factors.

SOME URGENT NEEDS IN f-VALUE DETERMINATIONS

Lawrence H. Aller

The development of improved, high-dispersion spectrographic equipment for solar and stellar work has enabled astronomers to get accurate data on line profiles not only at different points of the solar disk, for stars over a big range in apparent as well as absolute brightness, but also for peculiar stars, stars with extended envelopes, and gaseous nebulae. Spectroscopy

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of the solar corona and chromosphere from space platforms in the near future promises a wealth of data on the intensities, origins, and distributions of lines emitted from these regions, which so far have proven so difficult to interpret.

To assess these data it is essential that we know certain atomic parameters, cross-sections for electronic collisional excitations or de-excitations, collisional damping constants, and radiative transition probabilities or f-values. For studies of extended envelopes, the first and third mentioned must be known but the second is of no importance, while for the wings of strong lines the second and third are fundamental. In order to study deviations from LTE in the chromosphere and in extended stellar envelopes, appropriate parameters for collisional and radiative ionizations must also be known. Here we confine our attention to f-values, since without them we can make no progress at all.

We may measure either relative or absolute f-values. Absolute f-values are of course needed for all abundance work, but good relative f-values (particularly for elements of the iron group) are useful for getting excitation temperatures and for the construction of empirical curves of growth. Often, the situation is that absolute f-values are measured for strong resonance lines, while relative f-values are obtained for other lines. Then the absolute f-values of all lines may be obtained. Studies of this kind have been carried out for calcium and iron, for example, but many more investigations are needed.

It is not likely that all f-values we want can ever be measured, particularly for highly ionized atoms. Hence we must rely on theory but we must measure some lines that are (*a*) of astrophysical interest, (*b*) that can be measured by accurate techniques, and (*c*) can be calculated by theory. The best candidates for attention are probably such light elements as C,N,O, F,Ne, Si, P, S, Cl, and A whose lines appear in the Sun and hot stars. For these elements, absolute f-values can be obtained from arcs, shock tubes, life-time measurements, etc. These ions are sufficiently simple that the theory is of some use for them (see *e.g.* Biermann and Trefftz, Garstang, Layzer, Varsavsky, and Green). Even the Bates-Damgaard calculations are better than expected.

Experimentally, neutral neon and argon are easiest to handle, since they both exist in monatomic form. They can be studied in arcs (Olsen) or shock tubes (Doherty) and should be suitable for life-time measurements. Hence these gases should be useful as checks on or indicators of the validity of different types of experiments or theoretical methods. Lines of Ne I are observed in B stars and A I lines could probably be used in the infra-red. For higher stages of ionization, Ne II, A II, A III, etc. the f-values may be measured by magnetically driven shocks.

Of these elements silicon is probably the most important, since silicon lines are observed over a wide range of excitation from Si I to Si IV; hence they are useful as spectral class and temperature indicators. Around B2, lines of Si II, Si III, and Si IV all appear; hence these lines are useful for such studies as deviations from LTE.

Carbon, nitrogen, and oxygen in various stages of ionization are important in all stars from the Sun to those of spectral class O. The first few ionization stages can be obtained in high-voltage shock tubes; higher stages can be handled by theory. Because of their high cosmic abundance these elements are represented in a large variety of objects: normal stars, stars with extended envelopes, and gaseous nebulae. For example, the Orion nebula and certain planetaries such as NGC 7009 show recombination lines of O II; hence f-values are needed for the interpretation of such spectra.

Sulphur presents a particular problem; its forbidden lines S II and S III are among the strongest in gaseous nebulae. Reliable f-values for permitted lines of S I, S II, and S III are urgently needed. From a geochemical point of view, the sulphur content of the Sun as compared with that of chondrites and the lunar surface is of interest.

Experimental f-values are difficult to measure for chlorine and fluorine because of the corrosive character of these gases. Phosphorus is rare and relatively less important than the other elements.

For investigations of the satellite ultra-violet, we need f-values for resonance transitions of ionized atoms of abundant elements. Some of these f-values can be found by theory but many can be measured experimentally, in arcs and shock tubes, with spectrographs in a completely evacuated chamber.

Alkali and alkaline earth metals present special problems. Transition probabilities are well known for resonance lines of Li, Na, K, Rb, and Cs, but for Ca, Mg, and Sr there are discordances. Subordinate line f-values are needed for Na, K, Ca, and Mg, although a good set of f-values for subordinate lines of Ca have been obtained (Olsen). These elements are sufficiently simple that theoretical transition probabilities can also be computed. For example the coefficient of continuous absorption has been calculated for Ca I and Ca II.

Lines of the iron group of elements dominate the spectra of cooler stars. Because of the great number of levels and transitions involved, they are especially useful for studies of structures of solar and stellar atmospheres, temperature distributions, deviations from LTE, etc. Except for those of the very highest temperature, lines of ubiquitous iron appear in the spectra of all stars—even extended envelopes and gaseous nebulae where forbidden lines dominate. A curious and difficult problem is posed by the fact that although Fe I f-values appear to be well-established, the solar abundance of this element seems to come out too low as compared with chondritic meteorites, suggesting defects in our adopted model atmosphere or deviations from LTE. The absolute f-values have been measured (for elements of the iron group) only for resonance lines which are much too strong to be used for abundance studies. Hence one has to rely on weaker lines whose relative f-values have been measured; often these relative f-values are poorly determined, because the excitation temperature is in error or because of some cause such as deviations from LTE in the experiment. Examples of troubles of this sort, encountered for Cr, Ti, and Ni are given by Goldberg, Müller, and Aller (1960). Urgently needed are accurate measurements of absolute f-values for resonance lines of Sc, Ti, V, Cr, Mn, Co, Ni, and Cu—and good determinations of relative f-values, preferably by several different methods. Data are needed not only for neutral atoms, but also for ions, *e.g.* Ti II, V II, Cr II, and Fe II. Errors in some of these elements, *e.g.* copper, seem to be particularly serious. The solar abundance of Cu seems much too high (suggesting that the f-values adopted were correspondingly too low) as compared with chondritic meteorites.

Rare elements are represented in the Sun and stars only by their resonance or strong subordinate lines. Some elements, *e.g.* Sr, are represented by good lines in two stages of ionization (Sr I and Sr II). Hence their f-values should be carefully determined. Among elements of astrophysical interest in the second long period of the periodic table are Zr, Nb, Mo (Tc), Ru, Rh, Pd, Ag, Cd, In, Sn, Sb, and Ba. The most important of these heavier elements, lead, is under intensive investigation, but the discrepancies between various investigations thus far carried out point to some of the difficulties involved. The yttrium f-values show discordances of a factor of 500, indicating the necessity of careful experimental measurements. We are not yet in urgent need of f-values for rare earths, since the spectra of many of these metals and their ions have not yet been adequately analysed.

The problem is this: for a selected number of lines in a selected group of elements, we should determine by experiment and by theory (if possible) as accurate f-values as possible. Among the lighter elements, special emphasis should be placed on C, N, O, Ne, Si, and S in different

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ionization stages. For metals of the iron group we should investigate Ti, V, Cr, Mn, Ni, and Cu for both the neutral and singly ionized stages. It is urgent that the *f*-values be measured by more than one technique and every effort be made to eliminate systematic as well as accidental errors.

14*b*. SOUS-COMMISSION DES SPECTRES MOLECULAIRES D'INTERET ASTRONOMIQUE

Report of Meeting, 16 August 1961

PRESIDENT: P. Swings.
SECRETARY: J. G. Phillips.

The *Draft Report* of the Sub-Commission was adopted without amendment.

At the invitation of the President J. G. Phillips described the current status of the program of molecular band analysis being carried out on the Berkeley campus as a joint endeavor of the Physics and Astronomy Departments. After about a year and a half of extensive development, the program went into full production during the spring of 1960. The development consisted of the modernization of the 21-foot concave grating spectrograph of the Department of Physics by the purchase of a new grating from Bausch and Lomb, replacing and re-mounting the slits, and re-aligning the Paschen circle. An extensive series of tests resulted in the determination of observational procedures that would result in the production of spectrograms of the highest possible quality. The thorium halide electrodeless discharge excited by micro-waves was adopted as the source of comparison spectra. In addition, a semi-automatic measuring machine of the Tomkins and Fred type was constructed to aid in the measuring of the plates. Digitizing equipment on the measuring machine and the rental of an IBM 526 Summary Punch made it possible to punch the measurements and central line densities directly onto IBM cards for subsequent processing by the IBM 704 computer. Several programs were developed for the computer for the automatic reduction and analysis of the molecular bands on these spectrograms.

As of June 1961, the status of the production of band analyses is as follows:

1. *CN*. The analysis of the red system is nearing completion. Two sets of exposures were made, with a relatively low excitation discharge-tube source, and with a higher temperature enclosed arc. In all, 23 exposures have been made, comprising 100 plates, in addition to numerous test exposures. The spectral region covered runs from 4500 Å to 12000 Å. In this interval, 41 bands are suitable for measurement and analysis. The analysis of the low temperature discharge-tube plates is complete, and the analysis of the arc plates is nearing completion. On the discharge plates each of the eight resolvable branches of the bands can be followed, on the average, to the rotational quantum number $N=20$. The higher temperature arc source is making it possible for the majority of the branches to be extended to at least $N=60$.

A limited number of pre-publication copies of the discharge-tube results have been made available to those who can make immediate use of them. Negotiations are under way with the University of California Press for the publication of the complete table. They propose a volume with a page size of $8\frac{1}{2}\times 11$ ins., and suggest an initial printing of 1000 copies, 500 of which would be bound with hard covers.