ABSTRACT

A computer program for spectral synthesis has been developed, based on a list of data for atomic lines described by Kurucz, Peytremann, and Avrett. To demonstrate the usefulness of this program, we present a sample calculation of the region around the C IV resonance doublet at 155 nm, which is a feature in rocket and satellite spectra of B stars. The calculation indicates that the observed feature is a blend of many lines in addition to C IV, so that detailed calculations are necessary for the correct interpretation of the observational data.

Subject headings: atmospheres, stellar—line profiles—ultraviolet

Kurucz and Peytremann have calculated the gf-values for 1,760,000 atomic lines, which were then used to produce line-opacity distribution functions and a grid of line-blanketed model atmospheres for early-type stars (Kurucz, Peytremann, and Avrett 1973). The line list can be used as a starting point for detailed investigations of stellar spectra, but with several qualifications: First, the list is not complete, because (a) diatomic molecules are missing, (b) elements heavier than nickel are poorly represented, and (c) lines from configurations that do not have sufficient spectroscopic data could not be calculated. Furthermore, many lines in the list have wavelengths that are uncertain because they arise from theoretically determined energy levels, so they cannot be used for spectral synthesis. Finally, there is an error in the form of a large scatter in the gf-values, so, for detailed work, lines must be inspected individually. Despite these shortcomings, the line list is the most complete now available.

A program has been written for calculating spectra from this line list by combining parts of the distribution-function program for the line opacity with parts of the general model-atmosphere program ATLAS (Kurucz 1970). For each depth in a given model atmosphere, the total line opacity is calculated in a spectral interval at uniformly spaced points chosen such that there are several points per Doppler width in the Voigt profile for each line. To save time, a minimum cutoff of one-thousandth of the continuum opacity is used to limit the spread of the line wings. The wing opacity is due to radiative, van der Waals, and Stark broadening as described in Kurucz et al. (1973). At the beginning, middle, and end of each wavelength interval, the continuous opacity \( \kappa_c \) and the continuum source function \( S_c \) are calculated exactly, including scattering, and are used to determine either the continuum flux or intensity. Parabolic interpolation is used to find these quantities at any other wavelength in the interval. In calculating the spectrum, the monochromatic source function is approximated by

\[
S_v = (\kappa S_v + l_i S_i) / (\kappa_i + l_i)
\]

where \( l_i \) is the line opacity and \( S_i \) is the line source function, which is approximated by the Planck function \( B_v \).

In figure 1 we show a sample calculation for the C IV resonance doublet at 155 nm for the model with \( T_{\text{eff}} = 25,000^\circ \), \( \log g = 4 \) from Kurucz et al. (1973), which approximates a B2 star. In this calculation we assumed solar abundances (Withbroe 1971) and no microturbulence. Since B stars typically have high projected rotational velocities, it is necessary to broaden the calculated spectrum. S. R. Heap kindly rotated the spectrum to projected velocities of 50, 100, and 200 km s\(^{-1}\), using the method outlined by Huang and Struve (1960). In this procedure, the stellar disk is divided into a series of strips parallel to the rotation axis, and then the contribution of each strip to the observed flux profile is summed. In our case, the disk was divided into 400 strips. At \( v \sin i = 200 \text{ km s}^{-1} \), each strip corresponds to a wavelength step of about 0.5 pm (1 pm = 10\(^{-12}\) m), which is equal to the wavelength spacing of the synthesized spectrum. The figure shows only the central part of a longer wavelength interval so that the rotationally broadened profiles do not suffer from end effects.

The spectrum shown in figure 1 arises from the summed opacity of about 300 lines, many of which are Fe III. The two C IV resonance lines are indicated. We can draw several conclusions from this sample calculation:

1. Since an observed spectrum generally has an appearance similar to one of the rotated spectra shown in the figure, we can conclude that it is difficult or impossible to determine a "continuum" level or reliable equivalent widths from the features in observed spectra. Detailed calculation is necessary to determine the continuum level. For example, from the figure we see that at 200 km s\(^{-1}\) the maximum residual intensity is 0.83. Equivalent widths of the two absorption features would be underestimated by a factor of 2 if the continuum were drawn through that maximum.
2. The features themselves are blends of many lines so the equivalent width of a feature is not an easily interpreted quantity. The features depend on the relative abundances and ionization of C iv, Fe iii, etc. With spectral synthesis, it is possible to account for these effects.

3. The central wavelengths of the rotated features are a function of blending and rotational velocity. For example, the calculated feature at 154.8 nm is increasingly blueshifted from the C iv rest wavelength as the rotational velocity increases. At a rotational velocity of 200 km s\(^{-1}\), the blueshift would amount to 100 km s\(^{-1}\) if it were interpreted as a mass flow instead of a blending effect. A wavelength displacement must be carefully analyzed before it can be considered a Doppler shift caused by mass motion in the stellar atmosphere.

We expect to apply these synthesis techniques in quantitative detail to a wide range of problems, from solar spectral synthesis to interpretation of satellite and rocket spectra of early-type stars. With sufficient computer time, this program can also be used to synthesize galactic spectra and to predict redshifted spectral features.

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REFERENCES


