Cloudy

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The code was last described in Ferland et al. (1998), with a discussion of the chemistry network in Ferland, Fabian, & Johnstone (2002) and Abel et al. (2004). Cloudy is designed to go to LTE in the high density limit, the ISM limit at low densities, and to simulate a broad range of nebulae in between. The code is openly available on the web at `www.nublado.org`.

Some compromises were made to obtain the final results presented here. The grain physics employed by the code is described by van Hoof et al. (2004) and normally includes a full treatment of grain charging, heating and cooling, and thermal emission (including stochastic heating). Our treatment of grain surface recombination and the Schottky effect largely follows Draine & Sutin (1987). We extended this treatment to elements heavier than H by assuming that charge exchange between the grain/PAH and the ion always takes place in either direction as long as it is exothermic. We found this process to be very important in setting the abundance of H^+ and C^+. It was disabled for the comparisons presented here. Similarly, photoelectric heating by PAHs was included without including their effects on the electron density and the chemistry. The PAH abundance was chosen to give the best possible match to the Bakes & Tielens (1994) photoelectric heating rates. Electron recombination with grains/PAHs is normally included in the grain charge balance as well as the calculation of the electron density. This lowers the electron density noticeably in regions where carbon is neutral and has important ramifications for the chemistry in these regions. This effect is disabled for the present calculations.

Cloudy does not use the UMIST data base. We introduced an option to use UMIST to compute the results presented here. Normally the UMIST rates are used but only when the rates are an improvement over previously published values. The species H_2^*, HeH^+, and H^- are part of our usual

chemical network, but, for purposes of these calculations, their populations were set to zero.

We use radiative recombination rate coefficients from Ferland et al. (1992), which should be virtually exact for all temperatures. The UMIST database rates are a factor of 1.25 larger than the correct values at a temperature of 50 K. Cloudy treats all H-like and He-like atoms and ions as large multi-level systems. It would be difficult to impose an artificial recombination coefficient upon this system, and the correct values were used instead. This is the major source of the differences between our computed H^+ abundances and the majority of the other codes. A second major source of differences is the He charge transfer, which Stancil et al. (1998) notes is a factor of 4 smaller than the UMIST value. We did add an option to use the incorrect rates.

The code includes a full model of the H_2 molecule, which includes 1893 levels and predicts 524,387 lines (Shaw et al 2004). Final models use this molecule. Pumping to the excited electronic state by cosmic ray excited Lα was disabled for the comparison.

H^0 and He^0 have metastable $2s$ levels. We find that photoionization of these metastables by cosmic ray excited Lα is an important H and He ionization process. This was disabled for the purposes of this comparison.

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