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HYDROGENATED AMORPHOUS CARBON GRAINS AND THE 2175 Å INTERSTELLAR HUMP

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ABSTRACT

In this paper we present the first extinction spectra of carbon grains condensed in a hydrogen atmosphere to simulate the formation of dust particles in hydrogen-rich astrophysical environments. In order to assess the influence of hydrogen during grain formation unambiguously, experiments were performed in hydrogen-poor (Ar) and hydrogen-rich (H_2) atmospheres allowing the carbon vapor to condense homogeneously into grains.

The experimental data confirm the theoretical predictions on the lack of any feature in the ultraviolet spectra of fully hydrogenated amorphous carbon grains and clearly show the relevance of the different atmospheres during the condensation process. Our results support the idea that grains observed in the interstellar medium, which show a strong 2175 Å feature, have undergone some processing subsequent to their formation.

Subject headings: interstellar: grains — laboratory: spectra — ultraviolet: spectra

1. INTRODUCTION

The well-known 2175 Å interstellar extinction hump has been extensively studied since its discovery (Stecher 1965) and has been generally attributed to a plasmon resonance in small graphite grains (Gilra 1971). This resonance arises from collective excitation of the Π electrons and corresponds to the Π–Π* transition in graphite (Fink et al. 1984). Hydrogenation of the carbon localizes the Π electrons and reduces the collective Π resonance resulting in broadening and weakening of the absorption peak. Theoretical analyses (Hecht 1986; Sorrell 1990) based on laboratory data and astrophysical observations have already pointed out the importance of hydrogen in the formation and evolution of carbonaceous grains. In particular, they predict that in astronomical environments newly formed carbon grains may have high hydrogen concentrations and may not show the 2175 Å extinction hump.

The influence of hydrogen on the optical properties of carbon has already been experimentally studied, for both fresh and annealed hydrogen-containing carbon films formed by plasma deposition from hydrocarbon vapors (McKenzie et al. 1983; Fink et al. 1984). Other experiments have been specifically performed to compare the spectra of laboratory-synthesized carbonaceous materials to the 2175 Å interstellar extinction feature. Sakata et al. (1983) produced a quenched carbonaceous composite (QCC) material by condensing plasma-heated methane gas onto fused silica substrates. QCC, which contains a mixture of fine graphitic grains and hydrocarbons with conjugated double bonds, exhibits an absorption peak at 2170 ± 30 Å. Ogmen & Duley (1987) measured the optical properties of hydrogenated amorphous carbon (HAC) films, prepared by laser vaporization of bulk graphite into a low-pressure flow of He/H_2 gas mixture. The extinction of these HAC films increases with decreasing hydrogen content and shows a monotonic rise from 2 to 7 eV (6200–1771 Å). We note, however, that none of the above-mentioned investigations studied the spectral properties of carbonaceous grains formed by homogeneous condensation in a hydrogen-rich environment. This process should be similar to that by which interstellar grains are believed to form. Therefore we condensed carbon grains in Ar and H_2 atmospheres in order to study the effect of hydrogenation on their ultraviolet spectra. The results may be very useful in the interpretation of astronomical spectra.

2. EXPERIMENT AND RESULTS

The samples have been produced using two different methods: (1) by striking an arc discharge between two carbon electrodes, according to our standard technique already described elsewhere (Borghesi et al. 1983; Borghesi, Bussoletti, & Colangeli 1986); and (2) by focusing an excimer pulsed laser emitting at 308 nm onto the same type of carbon. The repetition rate of the laser was 9 Hz with an energy of 410 mJ pulse^{-1}. By using the two previous techniques, carbon vapors are formed in the production chamber and subsequently condense homogeneously to form solid grains. The particles are then collected on UV grade fused silica substrates, whose only purpose is to support the grains for the subsequent spectroscopical analysis. Several samples of each type were produced, and their transmission spectra were obtained using a Perkin Elmer Lambda 3 spectrophotometer in the range 2000–9000 Å. Transmission electron microscopy (TEM) was used to estimate the mean size of the hydrogenated particles and to identify diffracting phases.

The results of this analysis clearly show the following:

1. We have definitely produced grains (see Fig. 1);
2. They are clearly amorphous as demonstrated by the lack of any spot or fringe in their diffraction pattern;
3. Their shape is spheroidal with an average size close to that of carbon particles produced in Ar atmosphere (mean radius 40 Å; Borghesi et al. 1985; Colangeli et al. 1986); clustering is always present in any sample.

No major differences were seen in either the optical or the morphological properties of the particles by changing (1) the production method as previously described; (2) the amount of sample mass collected on the substrate; (3) the ambient pressure between 5 and 50 mbar; or (4) the distance (3–10 cm) between carbon electrodes (or target) and the fused silica substrates.

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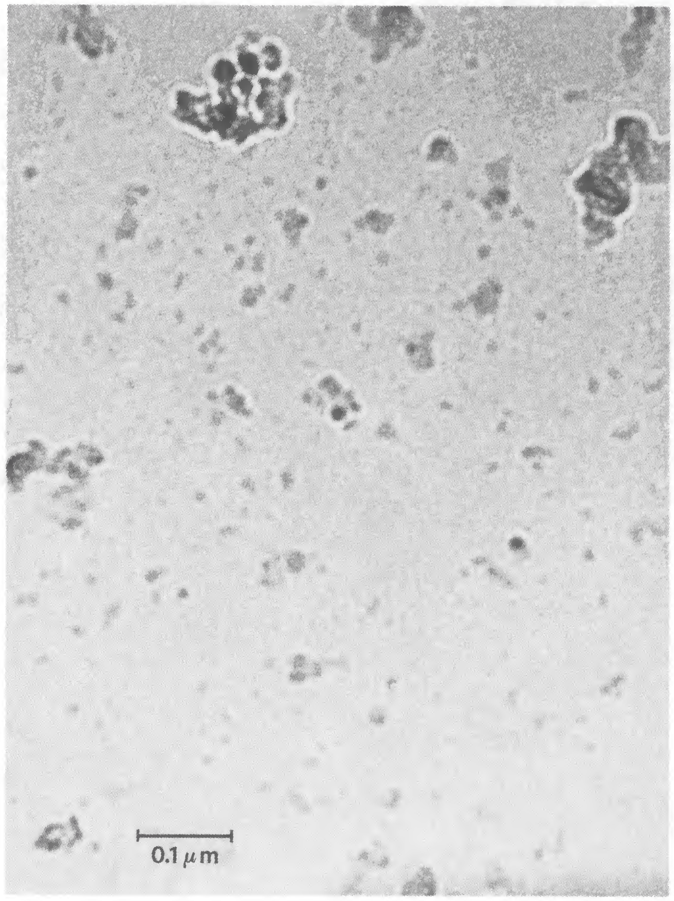

FIG. 1.—TEM image of hydrogenated amorphous carbon grains

On the contrary, the type of gas present during the grain condensation process seems to strongly affect the optical properties of the grains. In fact, although the particles produced under H_2 and Ar atmospheres are morphologically very similar, their UV spectra are remarkably different as shown in Figure 2. For carbon grains produced in Ar atmosphere we confirm the presence of an extinction peak around 2400 Å, similar in shape and position to the peak reported in previous papers (Borghesi et al. 1985; Colangeli et al. 1986; Bussoletti et al. 1987). No peak is present in the spectra of grains produced in H_2 atmospheres, which show an extinction increasing monotonically toward shorter wavelengths. We think therefore that the differences in spectra can be definitely attributed to the hydrogenation of the grains.

3. DISCUSSION AND CONCLUSION

Our results are consistent with theoretical models concerning hydrogenated amorphous carbon grains (Hecht 1986; Sorrell 1990). It is worthwhile to note, that all the featureless UV spectra of untreated carbonaceous materials reported up to now (Fink et al. 1984; Ogmen & Duley 1987) have been obtained on carbon films. It is unlikely that carbon film could be present in the interstellar medium, and theoretical models based on laboratory results concerning such materials could in

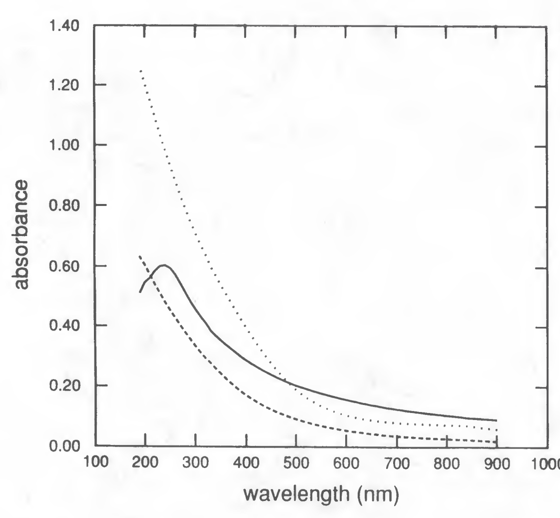

FIG. 2.—Absorption spectra of amorphous carbon grains produced in Ar (*solid line*) and H_2 (*dashed line*) atmospheres. The spectrum of a carbon film (*dotted line*) is also reported for comparison.

principle yield misleading conclusions. Moreover, in the laboratory, we have also studied a carbon film produced with the arc discharge technique by reducing the ambient gas pressure below ~0.1 mbar. The UV spectrum of the film appears featureless (see Fig. 2). We can then conclude that the UV spectra of carbon films do not show any hump, regardless of the presence of hydrogen during their formation. Therefore the absence of any hump in the spectra of hydrogenated carbon films found by other authors (Fink et al. 1984; Ogmen & Duley 1987) could also be due to the filmy structure of the samples.

For the first time the experiments show unambiguously that carbon grains formed in a hydrogen-rich environment do not show any extinction peak in their ultraviolet spectrum. On the contrary, an absorption peak around 2400 Å appears when particle formation occurs in a hydrogen-poor atmosphere. Since the grain formation process in our experiments is similar to condensation in astronomical environments, we do not expect freshly formed astronomical grains to exhibit a 2175 Å peak.

Our laboratory results may help to interpret the ultraviolet spectra of some carbon-rich sources. For example, Abell 30 (Greenstein 1981), R CrB and RY Sgr (Hecht et al. 1984), and HD 213985 (Buss, Lamers, & Snow 1989) have an absorption bump at 2300–2500 Å, while other objects such as Alpha Sco (Snow et al. 1987) and HD 89353 (Buss et al. 1989) do not show any detectable absorption band. The differences in spectra may be due to different hydrogen concentrations in the grain formation regions.

In conclusion, our data experimentally support current theoretical models and clearly show that a close relation exists between the presence of hydrogen during the grain formation process and the UV spectra of carbon particles: hydrogenation inhibits the appearance of an UV extinction peak. Grains may undergo subsequent processing to produce the observed 2175 Å feature. These first results, however, need further laboratory work to identify more clearly the exact nature of the carbon grains responsible for the 2175 Å interstellar bump.

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