ON THE POSSIBILITY OF LUMINESCENCE EMISSION OF INTERSTELLAR GRAINS

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Abstract. The possible occurrence of luminescence emission by different irradiated materials in interstellar space is discussed. It is shown by means of a model computation that the quantum efficiency of luminescence emission is high enough and can, in general, be detected in interstellar space. Further, it is argued that the wavelength-dependent intensity increase observed in the NGC 7023 reflection nebula at the distance of 3'4 from the illuminating star can be explained by luminescence emission of UV irradiated and Cu or rare-earth-doped glassy particles.

1. Introduction

The phenomenon of luminiscence emission occurs if the transitions between electronic states characteristic of the radiating matter set in. The emission spectrum is therefore independent upon the nature of the excitation for most materials. The electronic states involving impurities and structural imperfections (activators) in crystals are responsible for emission, which has a broad band spectrum lying in a longer wavelength region of the fundamental absorption edge of a crystal or glass. In pure insulators and semiconductors there can exist other states involving a pair consisting of an electron and positive hole, which is called an exciton. The excitons do not contribute to electrical conductivity but they do contribute to luminescent emission both in some excitation mechanism and in some radiative recombination processes (Williams, 1966).

There are several excitation processes needed for the respective luminescent emission. If luminescence emission originates in some grains in interstellar space, only photoluminescence and thermoluminescence are the probable mechanisms responsible for this emission. Photoluminescence is the fundamental process produced by electromagnetic radiation. Thermoluminescence does not refer to thermal excitation but to the thermal stimulation of emission produced by other processes, e.g. by photoluminescence. It is well known that luminescence is, in general, a low-temperature phenomenon. As has been mentioned above, the emission spectrum is independent of whether the excitation is from X, γ or UV radiation. For this reason one can expect that the physical conditions in interstellar space, i.e. temperature of grains and density of the excitation radiation near hot stars, are favourable to originating some luminescence phenomena in interstellar solid particles.
2. Luminescence Properties of the Materials of Interest to Astronomers

If luminescence is really present in interstellar space, it would be expected to appear as a product of irradiated Si, SiC, silicate-like and glassy-state materials, the occurrence of which is probable in interstellar space at very low temperatures.

If it is assumed that pure Si crystal grains exist in some relatively ‘young’ regions rich in the density of short wavelength irradiation at $T_0 \sim 3 \text{ K}$, then luminescence emission lines near $1.16 \mu$ should appear. This exciton recombination emission from Si specimens was first experimentally detected by Haynes (1967).

Exciton recombination radiation is based on the existence of the so-called excitonic molecule produced by binding two positive holes to two electrons, where positive holes play a role of positrons. As was experimentally proved by Haynes, a high concentration of excess electrons and holes is produced by UV irradiation. The exciton recombination radiation is proportional to exciton concentration and increases linearly with the irradiation intensity. The pronounced emission at $1.16 \mu$ is bound to the very low temperature $\sim 3 \text{ K}$.

In addition to pure Si and Ge crystals photoluminescent studies also give evidence for the existence of the electron-hole droplets in phosphorus-doped silicon in the impurity concentration range $9 \times 10^{15} \text{ cm}^{-3} < N_D < 4.3 \times 10^{19} \text{ cm}^{-3}$ at the temperature $T_g \sim 2 \text{ K}$ (Halliwell and Parsons, 1973).

The suspicion that a phenomenon like this can occur in some galactic regions can be seen in the excess infrared radiation at $0.9 \mu$ observed in the Orion belt (Johnson, 1968).

A possible detection of exciton radiation can, therefore, be expected to be present in regions near hot stars with low value of extinction for the colour $J$. Structural impurities do not exist in glasses in the same sense as in crystals. The excitation of a given luminescence is strongly influenced by the absorption features of the glass. Most multicomponent glasses containing alkali or alkaline-earth ions have large absorption coefficients for nearly all wavelengths smaller than 300 nm. Contrary to glasses, fused silica exhibits large transmissions for wavelengths near $200 \text{ nm}$. From the different types of luminescence centres, the copper-activated glasses may be of importance in astrophysical topics. Silicate, borate and phosphate glasses containing $0.1\%$ Cu excited at $313 \text{ nm}$ produce strong luminescence bands between 440 and $540 \text{ nm}$ (Rindone, 1966). As will be shown later, such an emission can account for the intensity excess at $540 \text{ nm}$ observed in NGC 7023. Silicon carbide is known to luminesce under ultraviolet excitation. The purest available crystals of SiC at $6 \text{ K}$ exhibit emission lines, the most intense lines being near $417 \text{ nm}$ (Dean, 1966).

Rare-earth doped glasses irradiated by UV light produce emission bands especially in the visible region. An extensive study of rare-earth activated silicate, borate and phosphate glasses of simple composition has been made by Karapetyan (1963). The most interesting is the luminescence of terbium activated glasses of the basic composition $\text{Na}_2\text{O} \cdot \text{CaO} \cdot 5 \text{ SiO}_2$. With $0.5\%$ Tb a large number of bands occur at $401,$