Double Valuedness of Specific Luminescence as a Function of Stopping Power*

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The dependence of specific luminescence on the stopping power of ^{16}O ions in thin-film plastic scintillators has been determined over a range of incident ion energies which bracket the maximum stopping power. The suggested double-valued dependence of specific luminescence has been confirmed. The pronounced drop in specific luminescence near maximum stopping power is understood in terms of electron pickup by the slowing ion.

I. INTRODUCTION

The dependence of the specific luminescence upon the stopping power (dE/dx) of heavy ionizing particles has been studied[1-4] over a wide range of energies, but always above the energy corresponding to maximum stopping power. A recent study[5] of $Z=1,2$ particles near this maximum dE/dx region suggests the double-valued dependence of specific luminescence on stopping power or specific energy loss. We confirm experimentally this double-valued dependence of specific luminescence on stopping power using ^{16}O ions as the ionizing particle.

II. EXPERIMENTAL

A thin-film scintillator detector[6] (TFD) was used to measure values proportional to luminescence and a solid-state detector (SSD) was used for incident- and residual-ion energy measurements. The experimental arrangement is described in Ref. 5. The ^{16}O ions, accelerated at the Florida State University tandem Van De Graaff facility, were scattered from a thin (0.1-mg/cm^2) nickel foil at selected angles to achieve a wide choice of energies of ions incident on the TFD-SSD assembly. Frequent calibration of the SSD and reference points for the TFD response were made with a radioactive-source emitting monoenergetic α particles at 8.78, 6.77, 6.28, 5.68, and 5.42 MeV. The SSD pulse height for ^{16}O ions was assumed to be linearly proportional to energy. At low energies (less than 10-MeV ^{16}O ions), the uncertainties in the energy-loss measurement caused by a detector "dead" layer were estimated to be less than 25 keV assuming a 40-μg/cm^2 gold layer.

III. RESULTS AND DISCUSSION

In Fig. 1 are shown the dependence of thin-film response (proportional to luminescence) and energy loss on the incident energy of the ^{16}O ions passing through a four-lamination (0.10-mg/cm^2) NE-102 film.[7] The maximum energy loss is observed to occur at 6 MeV, whereas the thin-film response reaches maximum value above 30 MeV. Similar results were obtained with an NE-111 scintillator[7] film. The energy region for which maximum TFD response occurs may be correlated with complete stripping of electrons from the transiting ion.[8,9] At these energies, significant variation in ion charge cannot occur, and we conclude that velocity is the dominant variable affecting luminescence yields.

A plot of thin-film response versus measured stopping power $\Delta E/\Delta x$ (Fig. 2) reveals the relative efficiency for conversion of the transiting-ion kinetic energy into detectable photons. Clearly, for a given value of specific energy loss, two relative values of luminescence (taken as proportional to TFD response) may apply, depending on whether the ion energy is below or above that corresponding to maximum stopping power, dE/dx. We characterize the complete luminescence dependence on stopping power with a closed "loop", for which

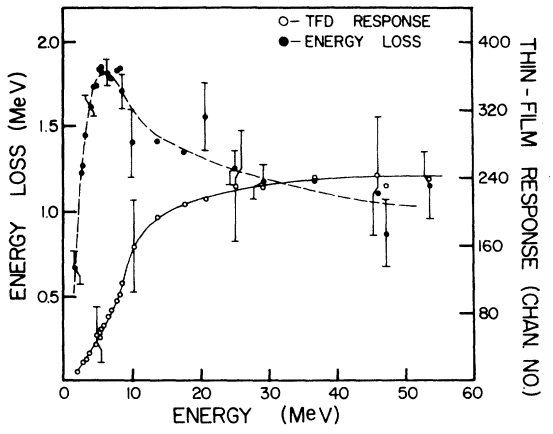

FIG. 1. Dependence of ion energy loss (solid circles) and thin-film response (open circles) on incident energy of transiting ^{16}O ions. Error bars on energy-loss data represent estimated statistical and systematic uncertainties. Limit bars on thin-film response represent the full width at half-maximum in the pulse-height peak distribution; the data points indicate the peak position.

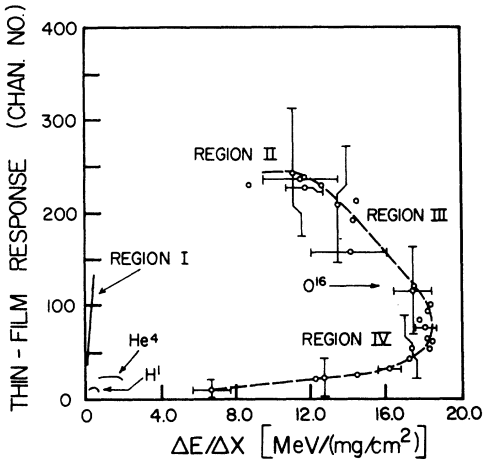

FIG. 2. Thin-film response to passing ^{16}O ions plotted as a function of specific energy loss. The response to lighter ions is shown for reference as solid curves. The straight solid line is an extension of the specific-luminescence-response dependence reported for high-energy protons (Ref. 5) and electrons (Ref. 2).

four zones or regions may be distinguished.

In region I, the specific luminescence is expected to be linearly proportional to specific energy loss; the well-known luminescence yields for lighter ions[1–3,5] bear this out. The ion is fully stripped in this region of very high velocities and low dE/dx values. The solid line, which is an extrapolation based on the luminescence yield for *high-velocity* protons[5] and electrons,[2] illustrates qualitatively this expected response.

Region II is characterized by a plateau or leveling off of the specific luminescence over a wide range of moderate ion energies. Ample experimental evidence for this plateau has been obtained with light ions, electrons, and, more recently, with accelerated nitrogen ions.[4] The deviation of this plateau from the linear extension of region I is postulated by Birks[10] to result from a local concentration of damaged molecules that act as exciton-quenching agents.

An alternate explanation proposed by Katz and Kobetich[11] applies the spatial distribution of ionization energy about the path of a rapidly moving ion to a "one-hit" saturation mechanism of luminescence centers. This latter mechanism, applied to a NaI(Tl) detector, clearly indicates a maximum in the luminescence response when plotted as a function of specific energy loss.[12] Other authors[13] have also discussed this effect for inorganic scintillators.

We choose to emphasize the importance of mean ion charge on the boundaries of this spatial distribution, i.e., in the determination of the "interaction" volume in which deposited energy is contained. More precisely, we refer to that volume about the ion-trajectory axis that is associated with luminescence phenomena. In region II, the transiting ion remains nearly completely stripped and the interaction volume varies only through a velocity dependence.

In regions III and IV we find the specific luminescence decreasing monotonically even while the specific energy loss passes through a maximum. The region in which the precipitous drop in luminescence begins (boundary between region II and III) is characterized by the onset of electron pickup by the fully charged ion.[8,9] It is apparent that the rapidly falling luminescence values in region III (and IV) may be correlated with decreased mean charge of the transiting ion. This explanation is consistent with the experimentally obtained dependence of specific luminescence on charges of heavy-mass ions.[14] In contrasting region IV with II, for a given specific energy loss, the distinction arises principally in the smaller interaction volume of region IV, this smaller volume itself resulting predominantly from reduced mean ion charge. Within this reduced volume either a saturation or quenching mechanism may be invoked to account for the reduced specific luminescence relative to that obtained in region II. However, no simple dependence of specific luminescence on specific energy loss is observed.

IV. SUMMARY

We have experimentally determined the dependence of specific luminescence on stopping power of ionizing ^{16}O particles in thin-film plastic NE-102 scintillators. The double-valued nature of the dependence of specific luminescence has been confirmed. The pronounced drop in specific luminescence near maximum stopping power is understood in terms of electron pickup by the slowing ion; this reduced average charge leads to smaller interaction volumes. These trends combine to give increased effective saturation or quenching effects leading to decreased specific luminescence at very low ion velocities. We view the specific energy loss as an inappropriate parameter for characterizing in simple terms the specific luminescence response. It is apparent that the ion velocity and effective ion charge (the latter being velocity dependent) are the elementary variables affecting this response.

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