matters arising

Dissociative recombination and meteor trains

SODIUM D-LINE emission arising from the cyclic process

$$Na + O_3 \xrightarrow{k_{Na}} NaO + O_2 \quad (1a)$$

$$NaO + O \longrightarrow Na^* + O_2 \quad (1b)$$

which was originally discussed[1] in connection with trains produced by 'fireball' meteors (brighter than visual magnitude −5) could, by virtue of an upward revision of the coefficient k_{Na} by three orders of magnitude[2], be significant for fainter visual meteors (down to zero magnitude)[3,4]. The observed brightness of a train in sodium light is expected to remain essentially constant until it is resolved by the observing instrument. Here we draw attention to dissociative recombination of metal monoxide ions as a source of train luminosity[5]. The ions are produced by the process

$$M^+ + O_3 \xrightarrow{k_+} MO^+ + O_2 \quad (2)$$

$$(M = Mg, Ca, Fe)$$

and the subsequent emission begins to decay immediately in quasi-exponential fashion. Emission may also be associated with the mutual neutralisation of M^+ ions with atmospheric negative ions[6], but is probably significantly weaker[5].

The rate-controlling process in both equation (1) and equation (2) is the oxidation by ozone, and the initial ratio of photon rates (per unit length of train) may be shown to be

$$(\text{Recombination emission/Sodium emission}) = (p_+ \beta_M \alpha_M k_+ / p_{Na} \alpha_{Na} k_{Na}) \quad (3)$$

where α is the linear density of ablated atoms indicated by the subscript, p_+ and p_{Na} are the appropriate mean photon yields per initial oxidation and β_M is the mean probability that an ablated M atom will be ionised. The relative contributions of these two components to visual or photographic data will depend largely on the spectral characteristics of the recombination emission. A recent examination of the role of unstable metal monoxide states in the dissociative recombination process has enabled me to estimate relative excitation cross sections for various possible dissociation products and hence obtain approximate relative multiplet strengths. The main contributors are found to be, using the identifying numbers of Moore[7], Mg I 1, 2, Ca I 1, 2, Fe I 1, 2, 3, 4, 5 and, to a lesser extent, other multiplets of Fe. The weighted mean wavelength of this radiation, allowing for the relative abundances of ion species in the train, is $\lambda \approx 430$ nm. If we take account of the response of the dark-adapted eye (scotopic condition) we find $\lambda_{eye} \approx 480$ nm (blue). There are also strong lines in the green and red.

From adopted elemental abundances for typical stony meteoroids we take $\alpha_M/\alpha_{Na} = 50$. The author's analysis gives $p_+ \approx 0.25$ and for p_{Na} we adopt 0.4 (ref. 4). β_M increases rapidly with increasing meteor speed, reaching ~0.06 at 60 km s^{-1} (after Sida[8]). With $k_{Na} = 3.3 \times 10^{-16}$ m^3 s^{-1} (ref. 2) and $k_+ = 2 \times 10^{-16}$ m^3 s^{-1} (a mean value[9]) we find the ratio in equation (3) to be small for slow meteors, increasing to unity for a speed of ~60 km s^{-1}. Allowing for the relative insensitivity of the dark-adapted eye at the sodium wavelength, the speed for which the two components are equally visible is ~45 km s^{-1}. Blue recombination multiplets are thus expected to dominate at higher meteor speeds, especially for the eye.

The emergence of recombination as a significant source of emission is consistent with the suggestion[3,10] that train luminosity associated with the fainter visual meteors is likely to be ionisation-linked. If no other processes are operative such trains might exhibit any hue from yellow through white to the complementary blue, and change with time depending on the decay characteristics of the two components. The fact that decays recorded photographically over the years generally agree with the predicted behaviour of the recombination component, can presumably be ascribed in part to the use of blue-sensitive film in much meteor work. Unfortunately, data against which these conclusions could be checked are scarce. Visual observations of faint short-lived trains tend to be unreliable and spectra, or even colour photographs, are difficult to obtain.

L. M. G. POOLE

Department of Physics,
University of Sheffield,
Sheffield, Yorks, UK

1. Baggaley, W. J. *Nature* **257**, 567–568 (1975).
2. Kolb, C. E. & Elgin, J. B. *Nature* **263**, 488–489 (1976)
3. Baggaley, W. J. *Nature* **267**, 376 (1977).
4. Baggaley, W. J. *The Observatory* **98**, 8–11 (1978).
5. Poole, L. M. G. *Planet. Space Sci.* (in the press).
6. Baggaley, W. J. *Bull. Astr. Inst. Czech.* **28**, 108–113 (1977).
7. Moore, C. E. *A Multiplet Table of Astrophysical Interest* (US Depart. of Commerce, NSRDS-NBS 40, 1972).
8. Sida, D. W. *Mon. Not. R. astr. Soc.* **143**, 37–47 (1969).
9. Poole, L. M. G. & Nicholson, T. F. *Planet. Space Sci.* **23**, 1262–1277 (1975).
10. Hughes, D. W. *Nature* **257**, 533–534 (1975).

BAGGALEY REPLIES–The oxide-reduction sodium cycle process seems to be incapable[1] of yielding observable meteor train emission for meteors fainter than visual magnitude about $-3\frac{1}{2}$ (velocity 45 km s^{-1}), and a catalytic cycle is incapable of exciting levels responsible for allowed transitions in meteoric atoms[2]. As some of the emission characteristics expected from the dissociative recombination of metal oxide ions are compatible with observations, the process seems to be an attractive candidate for train luminosity[3].

Although Poole suggests[3] that no useful meteor train spectral data exist, it is interesting that experienced observers in the last century using specially designed prismatic instruments did identify[4,5] spectrum line features (particularly Na I (ref. 1) and Mg I (ref. 2) in agreement with dissociative recombination) as well as a continuum in enduring trains. However, the conclusion[3] that emission in the blue (~4,300 Å) would dominate (due to Fe multiplets) contrasts with the photographic experience of early observers[6] that meteor trains failed to register on ortho films; and indeed the few published records of trains were obtained using film emulsions[6–8] with response extended to about 6,500 Å. Further, the only recent spectroscopic information is provided by Whipple's grating observation[6] of a train which revealed line emission in the red together with an organe-red continuum.

In dissociative recombination no rules are available to determine the proportion of reaction energy released as translational energy of the products. Although it is generally expected that, provided suitable states are available, all reaction energy emerges as atom excitation, the estimated[3] luminous efficiency (p_+) awaits experimental confirmation.

W. J. BAGGALEY

Department of Theoretical Physics,
1, Keble Rd, Oxford, UK

1. Baggaley, W. J. *Observatory* **98**, 8–11 (1978).
2. Baggaley, W. J. *Bull. astr. Inst. Czech.*, **27**, 244–246 (1976).
3. Poole, L. M. G. *Nature* **274**, 624 (1978).
4. Von Konkoly, N. *Mon. Not. R. astr. Soc.* **34**, 82–83 (1873).
5. Herschel, A. S. *Nature* **24**, 507–508 (1881).
6. Liller, W. & Whipple, F. L. in *Rocket Exploration of the Upper Atmosphere* (eds Boyd & Seaton) 112–130 (1954).
7. Hawkins, G. S. & Howard, W. E. *Astrophys. J.* **130**, 1003–1007 (1959).
8. Hughes, R. F. *Smithsonian Contr. Astrophys.* **3**, 79–94 (1959).

0028–0836/78/0274—0624$01.00