FURTHER SPECTRAL OBSERVATIONS OF GRENADE GLOW CLOUDS IN THE LOWER THERMOSPHERE

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Summary

The spectral energy distribution is given for the glow clouds resulting from the explosion of aluminized grenades in the range of altitude from 100 to 200 km. At night, over much of the spectral range from 300 to 800 nm, the spectrum is a continuum very similar to that of a black body at 4000–5000°K. At twilight, emissions resulting from resonant scattering of sunlight by Al, K, Ba, Na, and AlO are superimposed on, and dominate, the continuum.

I. Introduction

Woodbridge (1961) and Armstrong (1963) have discussed observations made of the chemiluminescent clouds that result when grenades containing aluminium are exploded either at night or at twilight in the upper atmosphere. Other authors have described similar observations of experiments using aluminized grenades and contaminants that include sodium, lithium, nitric oxide, and trimethyl aluminium.

We have made further observations of grenade glow clouds as part of the British Skylark rocket programme for upper atmosphere wind measurements. The present paper discusses the spectral observations made with a specially built grating spectroradiometer (Johnson 1965). The results of other measurements in the same series of experiments are presented elsewhere (Johnson *et al.* 1967).

The present spectral observations confirm and extend those of other workers. Almost the whole of the radiation observed at twilight is produced by resonant scattering of the incident solar flux. The origin of the night-time radiation remains uncertain.

II. Spectroradiometer

The spectroradiometer has interchangeable slits giving resolutions of 5 nm and 1 nm and uses an EMI type 9558QB photomultiplier detector feeding a logarithmic amplifier (Groves 1965). The output of the amplifier is recorded by a galvanometer oscillograph, together with wavelength and time markers. A scan from 290 to 820 nm takes about 10 sec, with 5 nm resolution. The instrument has been calibrated in absolute units against a standard tungsten ribbon lamp.

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Figure 1 shows typical records, one taken at night and one at twilight, both with 5 nm slits. For clarity in reproduction, return scans, in which grid lines appear every 10 nm, are shown. On forward scans, grid lines are recorded every nanometre and a lower scan speed is used (see Johnson 1965, Fig. 1). The occasional sharp noise peaks, characteristic of a photomultiplier, are easily recognized by the fast rise and relatively slow decay due to the properties of the logarithmic amplifier.

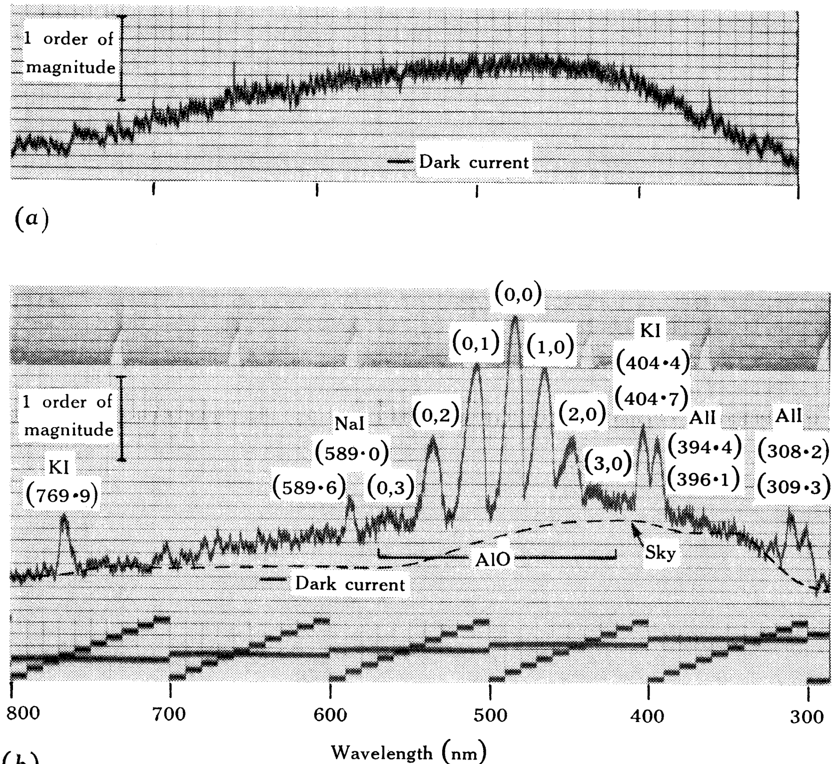

Fig. 1.—Typical spectroradiometer records for (*a*) night-time and (*b*) twilight.

III. Observations

Most of the observations have been of two types of aluminized grenades. The first, called type 1 by Armstrong (1963) and Ba-type in the present paper, contained a main charge of

aluminium powder	136 g,
barium nitrate	102 g,
potassium perchlorate	102 g,

together with a booster of 46 g TNT and 31 g powdered aluminium and an exploder of 20 g tetryl. The total aluminium content was therefore 167 g.

The second, called type 2 by Armstrong and K-type in the present paper, contained a main charge of

aluminium powder	135 g,
potassium nitrate	135 g,

with a booster and exploder as in the Ba-type, giving a total aluminium content of 166 g. A third aluminized contaminant was thermite, observed on one occasion from an otherwise unsuccessful experiment.

Figure 2 shows the clouds that have been recorded by the spectroradiometer. In many cases more than one record was obtained from each cloud. It is unfortunate that, as a result of unfavourable circumstances, there is no overlap in altitude between night-time and twilight results. We hope to complete the range of results in future work.

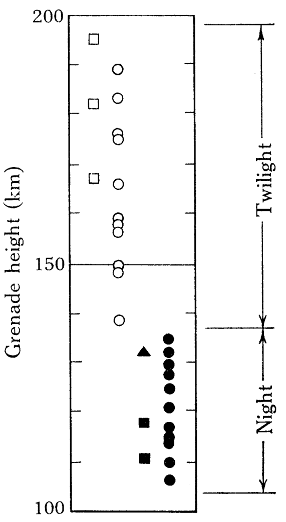

Fig. 2.—Grenade clouds observed:
□, ■ Ba-type;
○, ● K-type;
▲ thermite.

The observed spectra fall into three groups:

(1) a chemiluminescent continuum at night (Fig. 1(*a*));

(2) mainly resonant emissions at twilight (Fig. 1(*b*), in which the origins of the emissions are shown); and

(3) a combination of the two, in which the glow cloud is in the region between the full darkness of the Earth's umbra and full solar illumination. On occasions, the cloud was so close to the Earth's umbra that only the near infrared was transmitted through the atmosphere to the cloud and excited the 769·9 nm line of KI, which then appeared superimposed on a normal night-time continuum. Johnson (1965) has discussed the relationship of this type of spectrum to atmospheric extinction.

(*a*) *Night-time Clouds*

The spectral distribution curves for the three types of aluminized contaminant that have been observed, both at night and in the Earth's shadow at twilight, are not significantly different and a mean curve for 21 records is shown in Figure 3 (curve 1). The results have been corrected for the fact that the spectroradiometer can just detect the night sky over part of the wavelength range, and for atmospheric absorption between the cloud and the ground. Results taken with the 1 nm slit have shown no significant structure, so that any such structure, if present, is weak compared with the continuum. The continuum has similarities to that of black-body radiation, corresponding to temperatures of 4000–5000°K with a peak emission near a wavelength of 630 nm (see Fig. 3). More exact comparisons are not possible as the shape of the curve over the observed wavelength range is relatively insensitive to temperature. Also shown in Figure 3 (curve 3) is the equivalent of the photomultiplier dark current

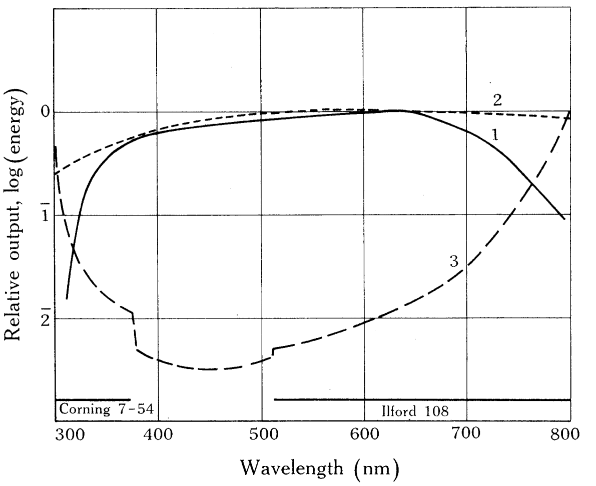

Fig. 3.—Chemiluminescent cloud output at night (curve 1, mean of 21 records). Also shown are the spectral distribution for black-body radiation at 5000°K (curve 2) and the photomultiplier dark current equivalent for the highest recorded intensity (curve 3).

for the highest intensity recorded. The steps in this curve are due to the insertion and removal of the filters indicated along the abscissa. The Corning ultraviolet transmitting filter removes visible light scattered by the grating, which, although a high quality replica, nevertheless scatters enough light to mask what otherwise would be easily detectable by the logarithmic amplifier. The Ilford filter removes the second-order spectrum of shorter wavelengths.

(*b*) *Twilight Clouds*

A typical low resolution (5 nm) record of the K-type grenade glow clouds is shown in Figure 1(*b*). Armstrong (1963) has observed the atomic lines of neutral potassium at 404·4 and 404·7 nm (unresolved in our records) and at 769·9 nm, but not the line at 766·5 nm that is absorbed by atmospheric oxygen, and has also observed the atomic lines of neutral aluminium at 394·4 and 396·1 nm (resolved in our high resolution (1 nm) records), as well as the (2, 0), (1, 0), (0, 0), (0, 1), (0, 2) band sequences of the $A^2\Sigma^+$—$X^2\Sigma^+$ transition of aluminium monoxide (AlO).

As shown in Figure 1(*b*) we have recorded other features in the early life of some clouds, namely, the neutral aluminium lines at 308·2 and 309·3 nm, the sodium D lines, and (weakly) the (3, 0) and (0, 3) sequences of AlO. The feature at about 301 nm has not been identified. It appears to be a line, but atmospheric absorption is increasing so rapidly towards shorter wavelengths (Fig. 3) that the true shape is doubtful.

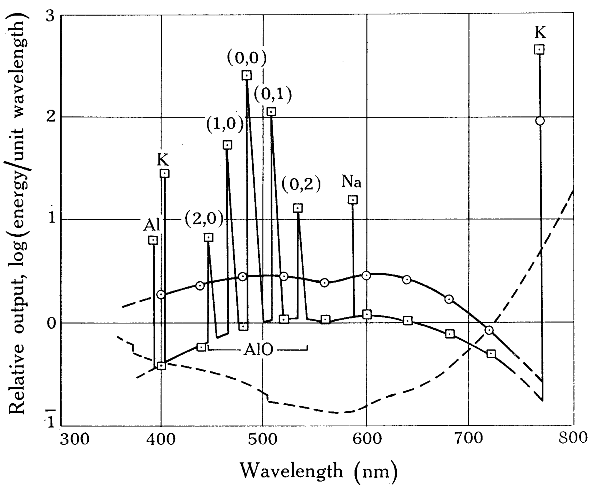

Fig. 4.—Chemiluminescent cloud outputs at twilight for two K-type glow clouds (⊙, dark, 125 km; ⊡, sunlit, 148 km). The dashed curve shows the sky–dark current equivalent.

For the Ba-type grenade glow clouds we have recorded the same emissions of Al, K, and AlO, together with the neutral barium line at 553·5 nm. This line decayed very rapidly compared with the other emissions. Armstrong's only observation of a Ba-type grenade was of one at 99·9 km, which lay underneath a K-type glow cloud at 133 km, so that he was unable to say with certainty whether there were any emissions from Al, K, or AlO present but concluded that, if present, they would have been weak. We have no records of either type of grenade at such a low altitude, but at higher altitudes the emissions from both types of grenades are essentially the same. Armstrong also recorded the 455·4 nm line of singly ionized barium, but we have not detected it with certainty because of low resolution and its proximity to the (2, 0) sequence of AlO.

A significant new observation is that there is a continuum underlying the resonant emissions in twilight glow clouds. Figure 1(*b*) also shows a record of the sky adjacent to the cloud, taken at about the same time as that of the cloud. The continuum is apparent above the radiation from the sky.

The continuum has essentially the same spectral distribution as the night-time continuum (see Fig. 3). Typical results are shown in Figure 4, where the total light outputs, corrected for atmospheric absorption between the cloud and the ground, of two K-type glow clouds in the same trial are plotted. The AlO bands, except for the band head intensities, are only shown schematically. One curve is for a sunlit glow cloud at 148 km and the second is for one of the type (3) above at 125 km. The two spectra were taken at about the same stage early in the lifetime of the clouds and, allowing for the known differing behaviour of night-time clouds at these two altitudes, the difference in output level cannot be taken as significant at present. Figure 4 also shows the sky and/or dark current equivalent for a continuum. For a band head it must be raised by 0·32 on the ordinate scale and for a line emission by 0·64.

We have not recorded extinction of resonant radiation as the Sun actually set on a glow cloud, though we can confirm Armstrong's observation that, in evening twilight after the Sun set on the cloud, the resonant radiations were no longer observed. However, we have recorded the reverse of this in a morning twilight firing. A K-type glow cloud at 139 km started by emitting a night-time continuum that behaved normally until the Sun rose. It then became very strong with all the normal resonant emissions and persisted for well over 15 min with very little reduction in radiance. It only disappeared when increasing sky radiance obscured it. Other observations have shown that the rate of change of total radiant output of clouds is almost zero at this altitude. They only disappear for other reasons: by the setting of the Sun or by increasing sky brightness, at evening and morning twilight respectively, or by diffusion at night. It is unfortunate that the underlying continuum was not known to exist at the time of this trial and so no low resolution records, which could have revealed it, were made.

IV. Discussion

Observations of night-time glow clouds confirm Armstrong's (1963) surmise that the night-time clouds give a continuum with no discrete emissions. This continuum is also emitted with about the same strength by twilight glow clouds. In these clouds, however, it is swamped by the potassium, aluminium, and aluminium monoxide emissions, which are due to resonant scattering of incident sunlight and which, of course, are affected by atmospheric extinction of the sunlight. The mechanism of the production of the continuum is still unknown but is probably due to chemiluminescence. Aluminium monoxide is obviously present in considerable quantities.

V. Acknowledgment

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VI. References

Armstrong, E. B. (1963).—*Planet. Space Sci.* **11**, 733–57.

Groves, J. R. V. (1965).—*J. scient. Instrum.* **42**, 430–1.

Johnson, E. R. (1965).—*J. geophys. Res.* **70**, 1275–7.

Johnson, E. R., Lloyd, K. H., Low, C. H., and Sheppard, L. M. (1967).—The radiant output of grenade glow clouds in the lower thermosphere. *Aust. J. Phys.* **20**(6) (in press).

Woodbridge, D. D. (1961).—"Chemical Reaction in the Lower and Upper Atmosphere." pp. 373–90. (Interscience: New York.)