

have been carried out by Durau², who found that prolonged heating was necessary to remove the last traces of water.

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¹ Dryden, J. S., and Meakins, R. J., *Nature*, **168**, 1121 (1951).

² Durau, F., *Ann. der Phys.*, **87**, 307 (1928).

Infra-Red Spectra of Coals and Coal Products

I WAS interested to read the comments of Gordon and his collaborators on the infra-red spectra of coal¹. The spectral range of our earlier work² was limited to 1,000–10,000 cm.⁻¹, because our first thin sections were mounted on fluorite plates with a transmission limit of 1,000 cm.⁻¹. Later work, as yet unpublished³, using the 'Nujol' dispersion technique⁴, extended the spectra of coals to 650 cm.⁻¹, the limit of the rock-salt prism spectrometers used.

Spectra of eighteen samples of bright coals (that is, mainly vitrain) of varying rank from Warwickshire, Northumberland, Yorkshire and South Wales were recorded. Humic acids, and pyridine and aniline extracts from several of the coals, were also examined. Most of the strong absorption bands were assigned to specific chemical groups present in the coal structure. The results and major conclusions are briefly summarized here.

The general level of absorption intensity was constant for the lower-rank coals. The general absorption intensity was higher for a coking coal and very much higher for a low-volatile steam coal. Gordon's spectrum of an anthracite¹ is almost devoid of structure except at the low-frequency end. Graphite examined in 'Nujol' at the same path-length as used for the coals was completely opaque from 5,000 cm.⁻¹ to 650 cm.⁻¹. A 'Nujol' dispersion c. 2 μ thick showed a continuous structureless absorption of 70–80 per cent over this spectral range. This marked increase in general absorption for the high-rank coals can be correlated with the development of optical anisotropy⁵, and with orientation and growth of crystalline regions found in X-ray diffraction studies⁶. It seems to mark the beginning of a transition from an aromatic structure (see below) towards a graphite-type structure.

The general similarity in the spectra of coals of all ranks examined (except anthracite¹) suggests that the molecular skeleton remains practically unchanged. As one might expect from the decrease in oxygen content with increase in rank, bands which can be assigned to oxygen-containing groups (OH, C=O, C—O—, etc.) decrease in intensity with increase of rank. The main absorption assigned to the C—O— stretching-frequency occurs in the region of 1,250 cm.⁻¹, suggesting that the OH groups are mainly phenolic rather than aliphatic hydroxyl.

The molecular structure seems very complex, but the C—H and —C=C— stretching frequencies, and the CH out-of-plane deformation frequencies near 880, 820 and 750 cm.⁻¹, when correlated with the spectra of a large variety of aromatic compounds⁷, indicate the presence of both single ring and con-

densed aromatic structures. Aliphatic CH₂- and CH₃-groups can be detected. Two carbonyl frequencies have been found; the stronger, near 1,690 cm.⁻¹, probably arises from aldehyde or keto-groups, while the second, near 1,730 cm.⁻¹, suggests the presence of a smaller proportion of ester groups.

For a low-rank coal, the spectrum of the material extracted by pyridine was practically identical with that of the parent coal.

A study of the hydroxyl frequencies in the spectra recorded suggests that hydrogen bonding between hydroxyl groups is one of the factors determining the physical structure of coals. Orchin and Storch⁸ have postulated a hydrogen-bonded structure for coal, following their work on solvent extraction. Dryden⁹ has briefly discussed the significance of the spectroscopic results and the part played by hydrogen bonding in the solvation of coals.

The humic acid spectra were clearly different from those of the parent coals, and had features in common with graphitic acid and mellitic acid (hexacarboxybenzene).

As Gordon *et al.* have noted¹, pitch extracts exhibit spectra bearing a remarkable resemblance to the coal spectra. Hadzi¹⁰ has studied the spectra of a variety of coal and tar extracts and has identified chemical groupings also found in the coal spectra.

The results summarized above, which were obtained several years ago, will be published in detail elsewhere.

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British Nylon Spinners, Ltd.,
Pontypool, Mon.
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¹ Gordon, Adams and Jenkins, *Nature*, **170**, 317 (1952).

² Cannon and Sutherland, *Trans. Farad. Soc.*, **41**, 280 (1945).

³ Cannon, B.C.U.R.A. Private Report, November 1946.

⁴ Cannon and Sutherland, *Nature*, **156**, 240 (1945).

⁵ Cannon and George, Conf. Ultrafine Structure of Coals and Cokes, B.C.U.R.A., 290 (1944).

⁶ Riley *et al.*, Conf. Ultrafine Structure of Coals and Cokes, B.C.U.R.A., 176 (1944) and later work.

⁷ Cannon and Sutherland, *Spectrochimica Acta*, **4**, 373 (1951).

⁸ Orchin and Storch, *Indust. Eng. Chem.*, **40**, 1385 (1948).

⁹ Dryden, *Chem. and Indust.*, 502 (1952).

¹⁰ Hadzi, Acad. Scient. Art. Slovenica, Class III, Series A, Ljubljana, **11**, 3 (1951).

A Trigonometric Series used in Physical Problems

IN connexion with a boundary-value problem in room acoustics, we were led to consider the following trigonometric series. It has been noted further that certain other trigonometric series encountered by K. S. Krishnan^{1,2} and L. S. Goddard³ in different physical situations can be obtained as special cases of the above series.

The series concerned is :

$$\sum_{n=1}^{\infty} \frac{\sin(n+\theta)x}{n+\theta} \cdot \frac{\sin(n+\phi)x}{n+\phi} = A(\theta, \phi; x), \text{ say,}$$

$$0 < x < \pi,$$