In addition, subsequent tectonic activity could have destroyed the characteristic spreading pattern.

Alternatively, a case can be made against the idea that the process of seafloor spreading has ever been operative in the Tasman Sea. Historical geological studies of this region¹¹⁻¹³ indicate that from the middle Palaeozoic through the Mesozoic the Lord Howe Rise and Norfolk Ridge were subaerial regions called "Tasmantis"¹⁴. Because a geosynclinal sedimentary environment existed throughout New Zealand and New Caledonia, this land mass has been proposed in order to provide a source of the geosynclinal sediments¹⁵. The idea that the Lord Howe Rise was formerly a positive land area, which has since subsided, would account for its nearly continental crust^{7,8} and apparent lack of Vine-Matthews linear magnetic anomalies. The high heat flow observed by Grim⁹ could have resulted from recent volcanic activity. Seismic profiler data¹⁵ show where outpourings of volcanics have occurred along the Lord Howe Rise. A more detailed survey should be conducted to resolve these two contradictory ideas concerning the source of the anomalous magnetic pattern found in the Tasman Sea.

Members of the Magnetism Division (US Naval Oceanographic Office) helped to gather the data. Dr P. R. Vogt reviewed the manuscript and made several constructive criticisms.

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Cosmology and Quantum Electrodynamics

SEVERAL attempts have been made to develop a quantum theory of the Wheeler-Feynman direct interparticle action electrodynamics. We have developed an approach using an *S*-matrix perturbation expansion. The importance of the approach is two-fold. First, it provides a welcome confirmation of the work of Hoyle and Narlikar¹⁻³; and second, it possesses the following distinct advantages: (i) it uses a formalism which is familiar in the conventional treatment of quantum electrodynamics; (ii) particle wave functions are second quantized; with some effort the theory can be made fully relativistic; (iii) it is completely general; a separation allows the influence of the universe to be taken into account in an overall way, without discussing the specific processes of the system under interest; in this way, the complete equivalence of the conventional and new theories is established for all processes and all orders of the perturbation; (iv) the simplicity and familiarity of many of the expressions provide a ready comparison with the conventional theory. The approach thus provides a foundation on which an axiomatic formu-

lation of direct interparticle action quantum electrodynamics may be constructed that is closely analogous to the conventional theory. In particular, the second quantization of the source particles allows the definition of operators analogous to the photon creation and destruction operators, in a way similar to that used by Klein⁴, and later by Heisenberg^{5,6} in conventional quantum electrodynamics.

The following is a brief outline of the *S*-matrix approach. The conventional perturbation expansion is modified in accordance with a suggestion made by Feynman⁷. The first term in the new expansion is examined. Contributions from all particles in the universe are included without reference to any particular model of the absorbing system (apart from the usual requirement of complete absorption). One immediately recovers a relation familiar from the conventional theory.

$$\langle 0 | A_\mu(x) A_\nu(x') | 0 \rangle = i D^-(x-x') \delta_{\mu\nu} \quad (1)$$

—with suitably defined *A*'s. Equation (1) leads straight away to the usual spontaneous transition rate for atoms which has been obtained by Hoyle and Narlikar³ using a similar theory.

A second, more intuitive treatment then reproduces equation (1) using an explicit model of the absorber system. Using this approach, an examination of the second term in the perturbation expansion leads quickly to the important result

$$\langle 0 | P[A_\mu(x) A_\nu(x')] | 0 \rangle = -i D_F(x-x') \delta_{\mu\nu} \quad (2)$$

P is the Dyson chronological operator.

The recovery of the Feynman propagator *D_F* enables the construction of Feynman graphs incorporating the analogues of internal photon lines. A simple generalization using results (1) and (2) allows the complete formal recovery of the usual *S*-matrix expansion and associated Feynman graphs, to all orders in the expansion. Equation (2) also leads in the usual fashion to the level shift formula for atomic energy levels which has been derived by Hoyle and Narlikar in their treatment³. Full details of this approach will be published shortly.

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Increased Luminance in the Direction of Reflex Reflexion—a Recently Observed Natural Phenomenon

LABORATORY studies and examination of aerial photographs have indicated that increased luminance in the direction of the reflex reflexion is a widely recurring phenomenon, which should be of interest to workers in several disciplines. The term reflex reflexion is used in accordance with the definition of the International Commission of Illumination: reflexion in which the path of the returning light lies close to the direction of the incident light, whatever the angle of incidence at the reflecting surface.

In 1962, Meacock *et al.*¹ drew attention to the increased luminance of (smoked) magnesium oxide in the direction of reflex reflexion, when incident light is normal to the surface. A repeat of these experiments, in which the

Fig. 1. Luminance indicatrices of mature isobilateral leaves of *E. regnans* (a), *E. obliqua* (b) and *E. goniocalyx* (c).

simple photo-multiplier was replaced by a Pritchard direct viewing photometer, gave similar results and showed that a maximum luminance factor occurs at 0° .

The study has been extended to include 30° , 45° and 60° angles of incidence. The luminance factors of magnesium oxide in the general direction of the light source were found to be greater in the direction of reflex reflexion, including a maximum at 0° ; the greatest rate of increase in luminance factors is between 2° and 0° , and the percentage increase in the luminance factors between $\pm 4^\circ$ and 0° is greatest when the incident angle is 60° and least with normal incidence. The 0° observation angle is provided by the line subtended from the centre of the image of the fully illuminated magnesium oxide to the centre of the viewing aperture of the photometer.

The same apparatus was used to investigate leaves of four eucalypt species, *E. goniocalyx*, *E. obliqua*, *E. radiata* and *E. regnans*, at angles of incidence 0° , 45° and 60° . The results for single leaves of three of these species are shown in Fig. 1 (45° incidence), and similar results were obtained for other leaves of each species. Clearly, the luminance factors have increased by approximately the same percentage between 4° and 0° viewing angles. For each leaf, the luminance factor starts increasing between 3° and 2° , then increases rapidly below $1^\circ/1.5^\circ$ and attains a maximum at 0° . The percentage increase in the luminance factors between 4° and 0° was greatest at 60° incidence and least at normal incidence. From Fig. 1, the arithmetic mean percentage increase between 2° and 0° is approximately 25 per cent, which is much greater than the percentage increase in the general direction of the light source at wider angles (for example, $\pm 15^\circ$ to $\pm 5^\circ$). Similar results were obtained for widely differing surfaces, including fascicles of pine needles (*Pinus radiata*) and tufted carpet.

These observations have implications in the fields of reflectance spectrophotometry and aerial photo-interpretation. An instrument having an Ulbricht integrating sphere will always have a small but important minor component of reflex reflexion back towards the light source, which is greater than previously assumed. For precise calculations, it therefore seems desirable to take this component into consideration. In aerial photo-interpretation, the direction of the component of reflex reflexion recorded for the leaves of eucalypt species

coincides with the central area of the frequently observed no-shadow zone on aerial photographs. This overall zone has been referred to as the "hot spot", "no-shadow point", "shadow point", "flare-point", "back-scatter" and Bröcken bows. It lies along a straight line subtended from the solar disk through the camera lens to the ground and is recorded on the photograph when the angular field of the camera covers a ground area beyond the point at which the line intersects the ground.

Although these terms are not entirely synonymous, the recorded zone has been attributed either to no-shadow on the ground or to back-scattering in the atmosphere. The present study, together with an extensive examination of appropriate aerial photographs, has indicated that at least the inner area of the zone, in conditions favouring high quality aerial photography, is primarily caused by increased luminance in the direction of reflex reflexion from diffuse surfaces. Thus a more appropriate term would be "reflex reflexion zone". The zone is absent on photographs covering water surfaces, but present over various crops, soil, rock types and plant communities in the same flight line; and very large-scale photographs (for example, 1/3,500) of forest contained an inner shadowless area within a larger zone of centripetally arranged shadows. The subtense angle of the reflex reflexion zone was commonly observed in the range of 1.25° to 2.5° over a wide range of photographic scales (1/3,500 to 1/80,000). The phenomenon of increased luminance in the direction of reflex reflexion seems to be associated with all naturally occurring diffuse surfaces.

Further investigations on the luminance of eucalypt leaves are being made. I thank Mr B. Cole and Mr A. Klein for helpful discussions and Mr Cole for the facilities provided.

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Wet Bulb Equilibrium in a Finite Process

WET bulb equilibrium between a liquid layer and a stream of air is established, in the absence of radiation, when the enthalpy of evaporation is entirely provided by heat transfer from the air stream. It is therefore possible to define an adiabatic surface, called here the *l*-surface, close to the interface and on the liquid side of it. For a control space bounded by an element of the *l*-surface, two cross-sectional planes normal to the air flow, and another adiabatic surface which may be the wall of a containing duct, the application of the steady flow energy equation and the liquid and vapour mass balance gives:

$$\frac{dh'}{dx} = h_{f,wb} \quad (1)$$

where h' is the enthalpy of the humid air in the bulk stream per mass of dry air, x is the mass ratio in the bulk stream (mass of vapour per mass of dry air) and $h_{f,wb}$ is the specific enthalpy of liquid at the *l*-surface.

Another surface, the *i*-surface, close to the interface but on the air side, is not adiabatic. Application of the energy and mass equations to a similar control space bounded by the *i*-surface gives

$$\frac{dh'}{dx} = \lambda \frac{c_p'(t_i - t)}{x_i - x} + h_{g,i} \quad (2)$$

where t is the temperature of the bulk air stream, t_i is the temperature at the *i*-surface, x_i is the mass ratio at