veloped. Since ball lightning floats, many physicists[2] believe the energy must be from an absorption of intense radio or other electromagnetic waves coming from outside the ball. The Soviet physicist P. L. Kapitza believes that some intense electromagnetic (nonnuclear) process feeds ball lightning. If radio waves are generated by such an electrical phenomenon, lightning cannot be pure dc as Paw U maintains. It is my personal opinion that under atmospheric conditions there is no such thing as pure dc.

Viemeister[2] quotes the great South African lightning expert, B. F. J. Schonland, as having observed lighted grass. He states, "If the thundercloud is particularly heavily charged even leaves and blades of grass may glow at the tips because of the intense ionization activity there." Surely if blades of grass and air (ball lightning) can glow in nature, insects can. No one has produced ball lightning in the laboratory (except possibly Nikola Tesla), but we have produced lighted insects under both ac and so-called dc conditions.

Further research in my laboratory (unpublished) demonstrated that once an insect is stimulated to emit St. Elmo's glow by a voltage surge of 1700–2000 V/cm, reduction of the voltage field to as low as 200–300 V/cm did not eliminate the glow. Apparently physiological gases are kept in the metastable emittance state by the well-known process of electrical hysteresis or feedback.

In regard to our quotation about blowing sand, blowing scales are far more pointed and abrasive than sand particles (Fig. 1). Entomologists understand that inhaling scales is more dangerous to the lungs than inhaling sand. Swarms of moths generate veritable storms of scales, since these structures are loosely attached to the moths (personal observations). If sand can light up by triboelectric effects, scales most certainly can—they are both dielectrics. There is little doubt that even in dry, clear weather small insects and scales driven by a fast jet stream would glow due to such triboelectric stimulation.

Swarms of insects are so usual in the upper atmosphere that entomologists[3] now speak of aerial plankton and the plankton zone (300 m and up, Ref. 3, p. 299). Insects have been taken in the plankton zone up to 4267 m (14,000 ft).[4] Over one square mile of ground in Louisiana, the air space may hold up to 93 million insects at one time.[4]

Radar researchers at NASA Wallops Island Flight Center and USDA engineers are studying insect swarms as dot angles.[5] Position plot image (PPI) scope returns (Fig. 2) demonstrate that even small species of insects tend to cluster in layers according to atmospheric conditions.

In 1969 I put insect traps on a 312-m (1200-ft) TV tower near Pelham, Georgia.[6] During migration season I obtained more insects above 76 m (250 ft) than below. I chose the spot because I knew from field experience that it should be a likely migration route. Strangely enough, 6 yr later in 1976, a Pelham resident took photographs, at the same spot, of a UFO display. True magazine[7] contacted me and published an article on my Applied Optics paper. In the magazine there was also an article on the Pelham sightings with photographs. The blobs of light look exactly like what they must be—lit-up insects.

Many species of insects are now known to ride convective storm fronts. This is a certainty in the case of the spruce budworm.[8] Such swarms may be 8–26 km (5–16 miles) long. It is quite conceivable that a voltage surge at one point in time and space might light up a portion of such a long swarm for a period and then move (or a different surge) and light up another portion of the long swarm. Such a phenomenon would give the impression to a ground observer of the light moving from point A to B at 48,279 km/h (30,000 mph) or even the speed of light.

I can make a good case for morning-bright daylight sightings being swarms of certain insect species. I do not intend to do so, for it has no practical application as does plotting insect migration routes from night sightings.

Paw U does not state his beliefs about UFOs being from an advanced extraterrestrial civilization, but my own convictions are those of Wesson.[9] In an elegant essay on the likelihood of an advanced extraterrestrial civilization, he points out that the existence of an electronic civilization equal to or ahead of our own is highly unlikely. His deduction is based partially on the fact that out of 250 billion suns in our galaxy, only 1%, or 2.5 billion, are likely to have planets climatically suited to biological life. The rest of his essay traces the history of various civilizations. He maintains that none of these civilizations, with the exception of the European, was able to sustain the high level of imaginative thought necessary to ensure their continuance. He equates the outburst of modern science with a rare combination of accidental circumstances that is unlikely to occur on other planets, at least not in synchronization with our scientific outburst. We will therefore be unable to contact any similar extraterrestrial civilization.

Based on our own work and the elegant reasoning of Wesson, I have very reluctantly come to the conclusion that the many unidentified flying object sightings are not visitors from outer space, but rather natural phenomena. Most are, no doubt, migrating or dispersing insects. Entomologists and agricultural engineers should use the Air Force UFO data to indicate placement of their radar units for migration studies.

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Insects as unidentified flying objects: author's reply to comments; 2

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My portion of the paper[1] critized by Kyaw Tha Paw U[2] dealt with the possibility that a corona discharge from an insect swarm could be visible under natural conditions. I believe this was adequately demonstrated, although I do agree with Paw U that these conditions are rather unusual. Even though such conditions are unusual, St. Elmo's fire has been reported many times from other objects.

As Paw U points out, a dc corona discharge attenuates rapidly, causing a blinking effect which makes radiant in-

tensity estimates of the discharge from a swarm difficult to obtain from radiant flux measurements on a single insect. To the naked eye the dc discharges were similar to the 2–3-kV/cm (not 5–7 kV/cm) ac discharges except for their duration, so the ac flux measurements were used to estimate the maximum possible distance of observation. Of course, in the middle of a thunderstorm, visibility might be zero, so further refinement of these measurements is of little value.

I agree with Paw U that although the insects-swarm hypothesis is plausible, it is by no means completely validated, and may never be completely validated to everyone's satisfaction.

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Field-widened Michelson spectrometer with no moving parts. Part 2

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A desirable property of interferometers used in the study of spectral distributions is large range of optical delay with no relative shift, or lateral shear, between the interfering beams. Spectrometers with this feature are insensitive to the spatial distributions of the source, and therefore they can collect radiation over a wider field angle. In the past, the difficulty of implementation has been attributed to the need for complex and expensive elements. Precise and synchronous motions of compensating wedges or relay elements in one leg of the interferometer have been typical requirements for achieving control of the optical delay with simultaneous compensation for the shift.

One of us[1] introduced a new method of sweeping a two-beam interferometer which in principle overcomes many of the drawbacks inherent in traditional methods. The advantage of the proposed concept is the manner in which sweeping is accomplished with no moving parts. An important improvement on a gas pressure system advanced by Ring and Schofield,[2] the concept involves introducing gases of differing refractive indices into the two legs of the interferometer with pressure equalization maintained by a servo system and by flexible membranes separating the two chambers (see Fig. 1 of Ref. 1). Combined with the additional field-widening of the corrected system, as claimed in Ref. 1, we obtain attractive results with an enhanced resolution–luminosity product and relatively simple design and operation.

Steel[3] points out that the configuration originally chosen to illustrate the sweeping mechanism is not fully field-widened. A meridional ray trace readily verifies there to be significant field curvature in the optical path difference (OPD) computation for the two legs of the interferometer. According to Ref. 3, an interferometer is fully field-widened when the
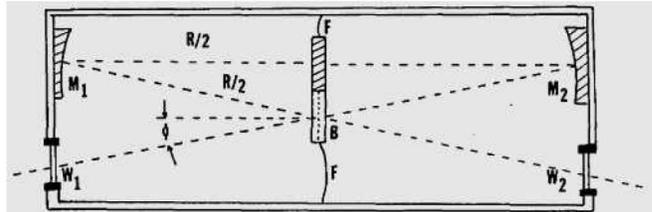

Fig. 1. Modified configuration for field-widened Michelson interferometer with no moving parts. M_1 and M_2, off-axis parabolas of vertex radius R; M_3, two-sided plane mirror; B, sandwich beam splitter; W_1 and W_2, entrance and exit windows; and F, flexible membrane separating the two halves of the enclosure.
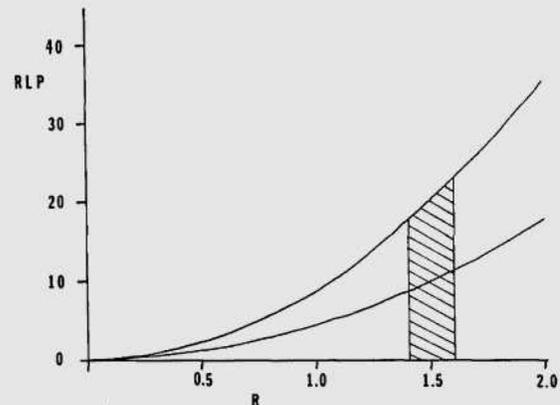

Fig. 2. Resolution–luminosity product, RLP plotted vs the optical radius of curvature R. Two values of the constant ϵ are used. For the upper curve $\epsilon = 1$ and for the lower curve $\epsilon = \frac{1}{2}$. The hatched region is explained in the text.

second-order terms in the OPD vanish. Steel[3] shows how to correct this condition with the arrangement shown in Fig. 2 of Ref. 3. As such, it becomes a field-widened Michelson interferometer with no moving parts.

In this Letter, we present the culmination of these earlier developments. Improvements have led to the scheme illustrated in Fig. 1. The figured beam-splitter cube described in Ref. 3 is replaced by a plane beam splitter and a flat mirror. The addition of the flat mirror allows two reflections from the single concave mirror in either leg of the device. All other important features of earlier concepts are retained.

The beam splitter shown in Fig. 1 is a parallel-plate sandwich with antireflection coatings on either side and 50% reflection and transmission coating at the sandwich interface. Scattering and absorption losses have been ignored for the analysis summarized below. This choice of beam splitter results in identical vacuum-equivalent geometries for both legs of the device. Because of the tilted beam splitter, the system does not have rotation symmetry.

For the analysis (see Appendix) a single meridional ray was traced through the system with optical path lengths computed to their quadratic dependence upon field angle. The reflecting interface of the beam splitter, marking the division and recombination planes of the interferometer, defines the entrance and exit pupils; these were the launching and receiving planes for the path-length calculations.

Assuming that the collecting optics are off-axis parabolas, the vacuum optical path length in either interferometer leg is computed to be