# The Anthracene-in-Benzene Chemical Light Meter[1]

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## *Abstract*

Several researchers have suggested that the anthracene-in-benzene chemical light meter is a useful tool for obtaining integrated solar insolation values. In studies of energy distribution under forest canopies and in small forest openings, the authors found this meter, with modifications, to be surprisingly sensitive and gratifyingly inexpensive. This paper describes the chemical light meter, emphasizing improvements in technique, equipment, and data interpretation, and points out its pertinent limitations. Several applications are discussed.

## Introduction

The measurement of solar radiation above, within, and below plant canopies has long been an important endeavor in ecological research. Much effort has been expended to develop economical light measuring devices capable of simultaneously sampling many points (4, 6). Of the methods now in use one of the more popular and useful is the technique for measuring light energy via the photo-conversion of anthracene in benzene solution to dianthracene (1, 3, 5).

Briefly, the technique is based on the fact that anthracene in benzene will polymerize into insoluble dianthracene upon exposure to sunlight. Glass vials of a known concentration of anthracene in benzene are exposed to the light environment of a particular location for a designated period of time and then analyzed to determine the concentration of unconverted anthracene remaining in solution. This analysis is made by filtering the contents of an exposed vial to remove the insoluble dianthracene and then determining the concentration of the remaining anthracene with a spectrophotometer. The decrease in concentration is then related to the amount of light energy received by using a predetermined calibration curve.

## Advantages and Limitations

As with any technique certain advantages and limitations must be considered. The anthracene chemical light meter measures the cumulative amount of light energy reaching a particular location over a given period of time without requiring additional recording equipment. The added benefit of small size (*ca.* 1″ x 2″) allows the researcher to sample almost any location without disturbance. However, instantaneous values of light intensity are unavailable and additional instrumentation, such as a photometer or pyranometer, is necessary if such data are desired.

The technique is relatively inexpensive except for the spectrophotometer, which is available in most laboratories. We have determined,

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for example, that after the initial acquisition of a limited amount of glassware, the cost per vial per sample run was about 2 cents. This low cost allows the researcher an almost unlimited number of points which can be sampled simultaneously. However, one cost not included, and a definite drawback of the technique, is the large number of laboratory man-hours required in preparing and analyzing the chemical light meters. We found that a single sample run of 400 meters (vials) would involve about 20 laboratory man-hours.

The most serious limitation of this technique, as well as other proposed chemical light meters, is that the absorption regions of the chemicals used are in ultraviolet light regions, which does not correspond with chlorophyll absorption. The absorption spectrum for anthracene in benzene is less than 390 nm with 100% absorption at about 345 to 360 and at 379 nm. There is no absorption in the visible or near-red spectrums (410 to 1000 nm) (5).

For this meter to be useful as a device for determining total incoming energy over a given time period, it would seem necessary that the ultraviolet light be a constant fraction of that total. According to several authors (6), except for very low energy periods at or near sunrise and sunset, ultraviolet light makes up a nearly constant part of the total daily incoming light energy. However, this relationship may change radically below a plant canopy since some species spectrally modify sunlight as it passes through their foliage. The canopies of some hardwood species, for example, are reported to spectrally modify sunlight; pine canopies on the other hand are more generally regarded to act as neutral filters (2, 6).

Criticism has been voiced about the failure of many light meters, including chemical ones, to quantify directly the photosynthetically active radiation. This may be valid if one intends only to study photosynthesis. However, much attention today is being given to total energy balances, which correspondingly involve the entire spectrum. Although the anthracene chemical light meter is sensitive only in the ultraviolet wavelengths, the meter correlates well with instruments measuring all incoming solar energy (6).

## Improvements in the Technique

A literature search failed to reveal the best type of vial to be used. Our studies showed that 20 ml scintillation vials with foil-lined screw caps (Packard Inst. Co.) performed well because of their strength and durability, consistency in spectral properties, prevention of benzene corrosion, and their small size. The problems of leakage and evaporation losses of benzene, experienced by other researchers, were not encountered with these vials. The cardboard shipping trays were also found to make excellent vial holders when inserted into easily designed, wooden light-tight boxes for field use.

Variations in recommended concentration from 0.1 to 6.0 g of of anthracene/l of benzene were also found in the literature. Since spectrophotometers cannot usually be used to determine concentrations much above 0.1 g/l, higher concentrations must first be diluted. Even after a full day's exposure to direct sunlight, we found it necessary to dilute the higher initial concentration solutions before insertion in the spectrophotometer. Since the dilution operation must be performed individually on the contents of each vial after it has been filtered, this is a cumbersome, time-consuming and possibly error-filled process. Rediske *et al.* (5) suggested by-passing the dilution procedure by using a starting concentration near the upper limits of sensitivity of one's spectrophotometer. Figure 1 shows that with 0.1 g/l anthracene in benzene as a starting concentration, the calibration curve for our spectrophotometer was linear over the entire range of interest. Higher concentrations showed the same linear relationship. The light energy flux for use in this calibration curve was determined by an Eppley pyranometer.

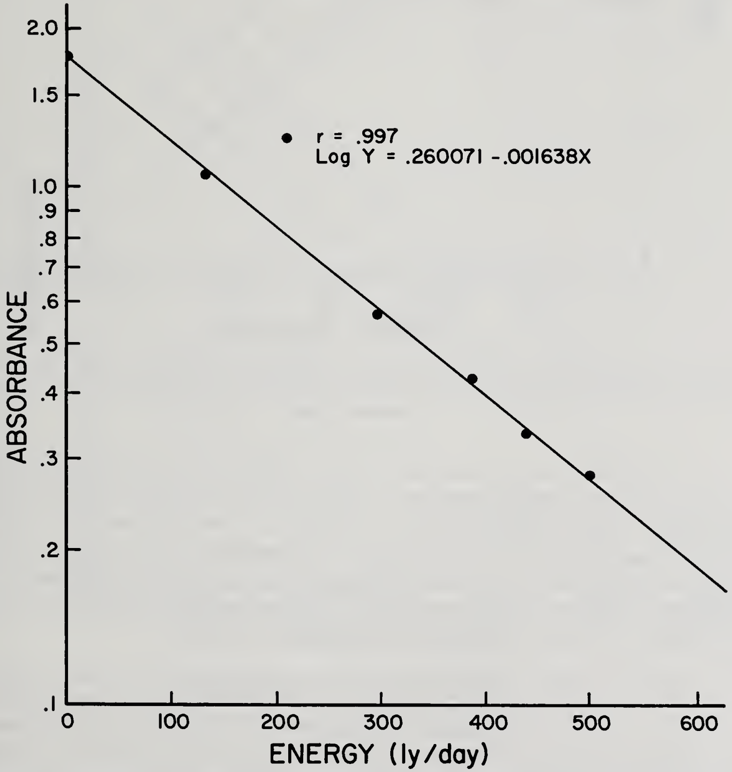

FIGURE 1. *Calibration curve showing linear relationship with 0.1 g/1 anthracene starting concentration.*

A statistical test of the slope of the calibration curve as affected by initial solution concentration showed that slope was not affected (99% confidence level) for initial concentrations of 70, 80, 90 and 100 mg/l.

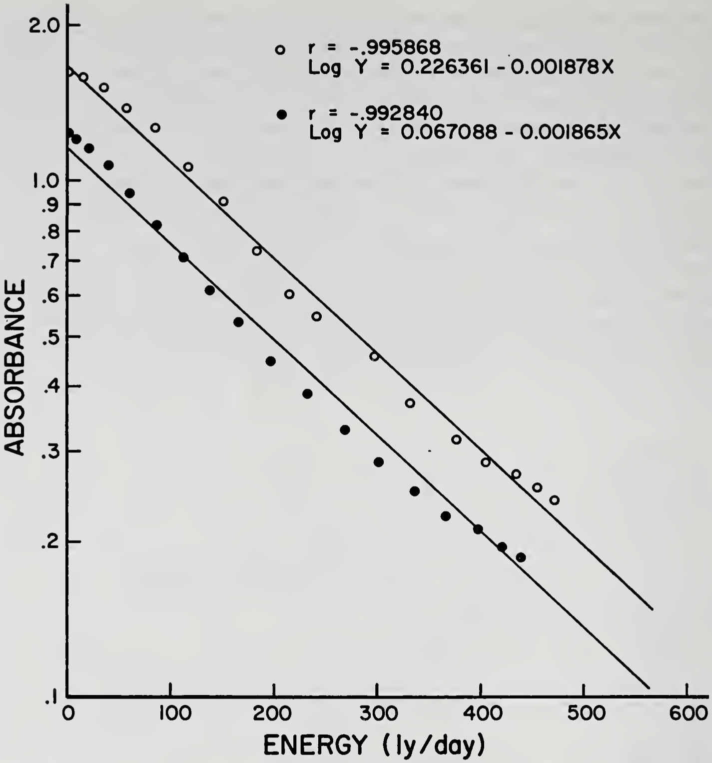

FIGURE 2. *Two calibration curves for vials on a burlap background. Upper curve represents 90 mg/1 starting concentration and the lower curve represents 70 mg/1 starting concentration.*

A test was also conducted on the effect on the calibration curve of the type of background over which the vial was exposed during calibration runs. Figures 2 and 3 illustrate these effects for a burlap surface background and the diffuse background surrounding a hanging vial. The two sets of calibration curves have very different slopes. Calibration curves obviously should be determined using the same materials and set-up as that to be followed in the field.

## Applications of the Techniques

One of the current research projects of the Department of Forestry and Conservation at Purdue University deals with the light regime in small forest openings. A 50 x 60-foot rectangular opening, long axis aligned north and south, was cut in a 22-year old red pine (*Pinus resinosa,* Ait.) plantation which averages 35 feet tall and has complete crown closure. To determine the levels and patterns of solar energy being received in the opening, chemical light meters were installed along three east-west transects across the opening. To check on the ability of the anthracene meters to accurately measure light in the shaded portions, an Eppley pyranometer was also located in the opening. Results for a single time period from sunrise to solar noon on a clear day are presented in Table 1. The table shows that the sample points on the west side of the opening did record the most energy as would be expected, as well as a decreasing trend in energy from west to east to a point (-2.0 feet) inside the pine stand. Also shown by the data are the comparable results of the chemical meters located 1.5 feet north and south of the Eppley. Each of these meters measured 44 ly which is within 1 ly of the 45 ly measured by the Eppley.

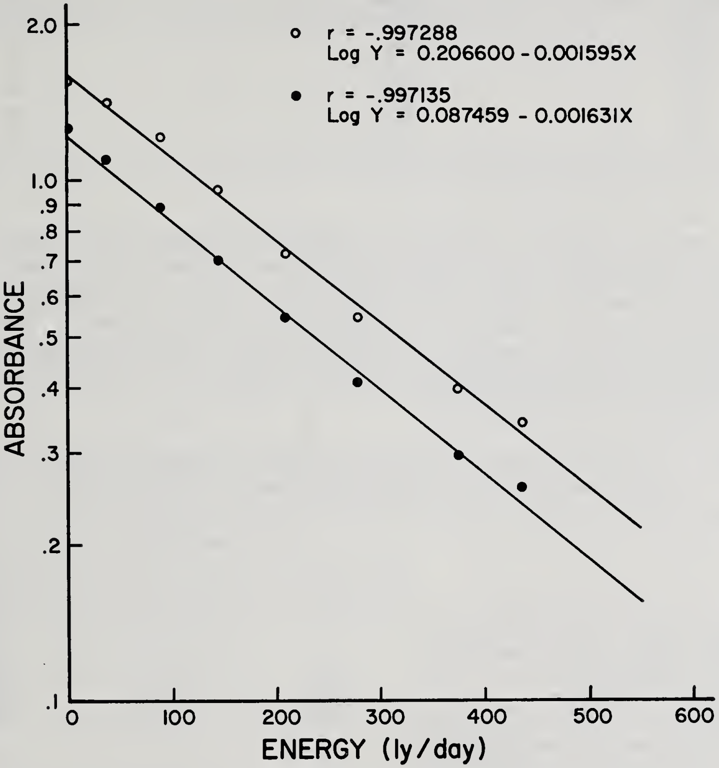

Figure 3. *Two calibration curves for hanging vials with a diffuse background. Upper curve represents 90 mg/1 starting concentration and the lower curve represents 70 mg/1 starting concentration.*

Another portion of the research is a study of the variability in the daily light energy received under a dense pine forest canopy. In the same red pine plantation as previously described, data were collected using anthracene meters for three separate days. The objective was to sample the variability in relative light intensity so that the proper number of sample points to provide statistical reliability could be calculated.

TABLE 1. *Integrated energy values (in langleys) obtained along east-west transects of a forest opening using chemical light meters. Data obtained for time period from sunrise to solar noon, August 28, 1973.*

| Distance of Sample Points from East Edge of Opening in Feet | Location of Transect from South Edge of Opening in Feet | | |
|---|---|---|---|
| | 28.5 | 30.0 | 31.5 |
| —2.0 | 24 | -- | 24 |
| 1.0 | 33 | 36 | 36 |
| 2.5 | 44 | 45[1] | 44 |
| 4.0 | 47 | 46 | 50 |
| 7.0 | 65 | -- | 63 |
| 13.0 | 92 | -- | 92 |
| 19.0 | 112 | -- | 119 |
| 25.0 | 132 | -- | 132 |
| 31.0 | 147 | -- | 144 |
| 37.0 | 130 | -- | 142 |
| 43.0 | 139 | -- | 141 |
| 49.0 | 121 | -- | 123 |

[1] Obtained with an Eppley Pyranometer

Table 2 gives the summaries of the three sample runs. Mean relative light, which is the percentage of light received in the open, was used so that the three days could be compared successfully. The calculation of the adequate sample size in the last line of Table 2 indicates that the variances of the three test runs were close. These numbers are in good agreement with the estimated 10 samples commonly suggested in the literature.

TABLE 2. *Statistical summary of ground level light measurement data under a 22-year old red pine stand with full canopy closure using chemical light meters.*

| | Date of test | | |
|---|---|---|---|
| | June 14, 1973 | August 4, 1973 | August 22, 1973 |
| Sample size | 20 | 20 | 24 |
| Mean relative light as compared to that in the open | .0170 | .0121 | .0128 |
| Coefficient of variation | .3529 | .3471 | .2656 |
| Variance | .000036 | .000018 | .000012 |
| Calculated sample size assuming a 20% error about the true mean, $t \cong 2$ | 12 | 12 | 8 |

## Literature Cited

1. DORE, W. G. 1958. A simple chemical light meter. Ecology 39:151-152.

2. GAY, LLOYD W. 1971. The forest radiation budget—A review. Third E. Forest Meteorol. Conf., Coll. Forestry, S.U.N.Y., Syracuse. 15 p.

3. MARQUIS, D. A., and G. YELENOSKY. 1962. A chemical light meter for forest research. U.S. Forest Serv., N. E. Forest Exp. Sta. Pap. 165. 25 p.

4. PERRY, T. O., H. E. SELLERS, and C. O. BLANCHARD. 1969. Estimation of photosynthetically active radiation under a forest canopy with chlorophyll extracts and from basal area measurements. Ecology 50:39-44.

5. REDISKE, J. H., D. C. NICHOLSON, and G. R. STAEBLER. 1963. Anthracene technique for evaluating canopy density following application of herbicides. For. Sci. 9:339-343.

6. REIFSNYDER, W. E., and H. W. LULL. 1965. Radiant energy in relation to forests. U.S. Forest Serv., Tech. Bull. 1344, Washington, D.C. 111 p.