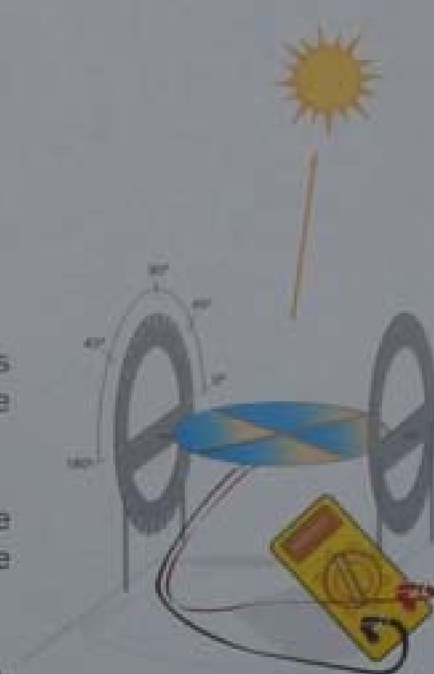
Experiment 01

Lambert's Law and the Bright Sky



Objective

Lambert's Law of Illumination:

(a) The illumination of a surface from a point source is inversely proportional to the square of the distance between the surface and the point source.

(b) The illumination of a surface is proportional to the cosine of the angle between the incident light rays and the normal to the surface.

This experiment uses part (b) and shows that the illumination of a solar module is closely proportional to the cosine of the angle between the incident light rays and the normal to the surface. Students graph the data and observe a cosine type curve. By adjusting the amplitude and phase of a numerically calculated cosine curve, the student tries to match the experimental data to a predicted value. The student should be able to explain the non-zero data values recorded when the solar module is turned away from the sun.

Value

Students build an experimental device that gives real-world measurements. Lambert's Law (b) is introduced as a concept and the experimental data is compared with the values of a computer generated cosine curve. The student is asked to explain the difference between measured and predicted values. The student should realise that the angle of incidence for light rays illuminating a solar module varies throughout the day. This difference in angle can be used with Lambert's law to estimate the total amount of energy available from a solar module in a day.

Notes

This experiment uses a fundamental principle of a solar module. The short circuit current of the solar module is directly proportional to the amount of light striking the module.

If the sun's rays were perfectly parallel and there were no scattering of light by the atmosphere (the sky itself being jet black) or reflections from objects, then the student's graph would show a cosine section. The data will represent a superposition of multiple light sources as the blue sky itself is a diffuse light source and there is substantial reflection of light off the objects local to the solar module.

The dominant factor in the data is caused from the parallel light of the sun striking the solar module. The other light sources (blue sky and reflections from nearby objects) become especially evident at points on the graph where the solar module has no direct sunlight striking it. The current from the solar module does not drop to zero even when the solar module is directly facing the earth.

EXPERIMENTS

When setting up the experiment make sure that the student has the protractors parallel to the sun's rays. This can be accomplished by making sure that each protractor casts a shadow that is a thin line on the ground.

Once the student has used a spreadsheet to graph the data, the student should determine the data point with the maximum current. That value is then used to generate a cosine function with its maximum amplitude matching the maximum current from the data. The generated cosine values are then graphed together with the experimental data and the corresponding shapes and values are compared.

The cosine graph is generated using: (maximum current value)*cos(protractor angle minus the recorded angle of maximum current data point) for each data set. This will create a cosine with the same maximum amplitude as the observed data and will move its phase so that it will superimpose the recorded data. Remember to change degrees to radians in the spreadsheet calculations.

The student may need to add an additional five degrees to the maximum current data point angle to best match the cosine curve to the data; 120 degrees becomes 125 degrees, to take into account the coarseness (10 degree increments) of the measurements.

Angle zero of the measurements is with the solar module horizontal and facing towards the earth. There should be measurable current from the solar module even at angle zero.

Protractors, solar module and multimeter ready for measurement.

Equipment

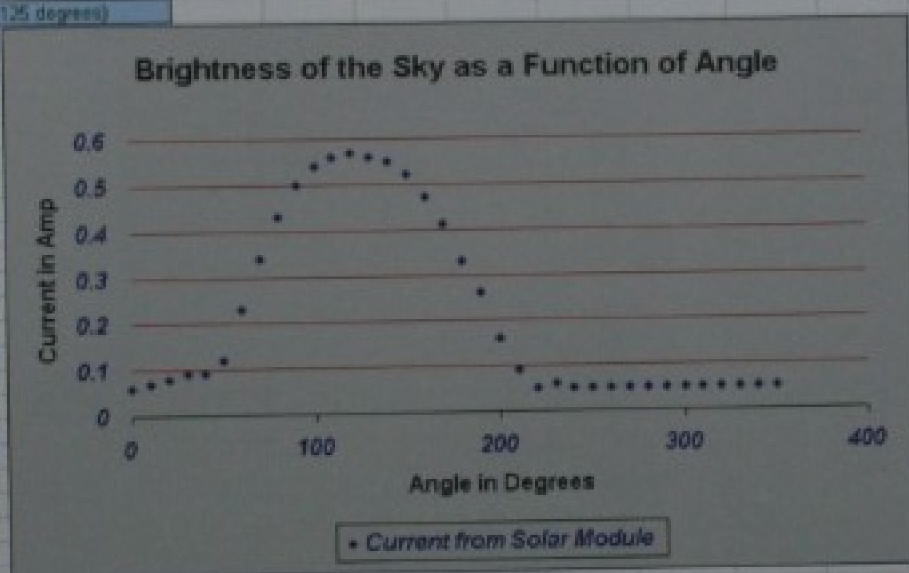
One 4-cell solar module, one multimeter with alligator clips, two circular protractors, coat hanger wire, tape, and two small squares of cardboard (used to hold the solar module on the protractors so that it can rotate freely). The multimeter is used in "current mode".

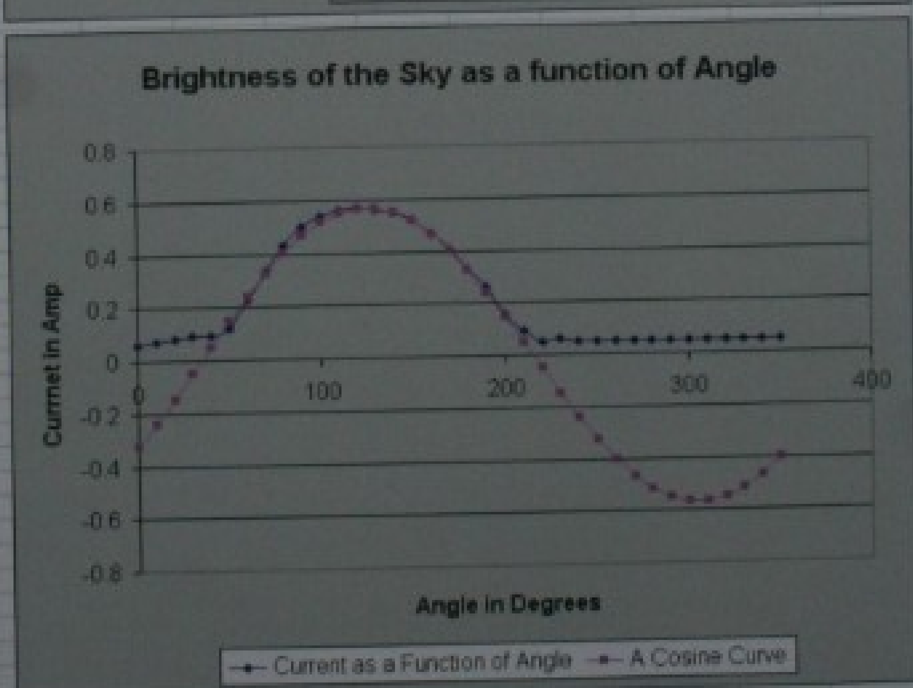
Method 1 Comparison to a Cosine Graph

Students use a small solar module consisting of four solar cells in series as a linear light sensor. Each of two circular protractors are modified by placing two short lengths of coat hanger tangential to their edges allowing them to be easily pushed into the ground. A small piece of cardboard with a hole in it is placed near the centre point on each protractor allowing the solar module to be suspended on a shaft between the two protractors. Start with the solar module facing down towards the earth and record the angle (zero being horizontal) and the short circuit current from the solar module. Tilt the solar module ten degrees and record the angle and the new short circuit current. Continue rotating the solar module by 10 degrees until thirty-five angle and current measurements are taken. The solar module will have rotated a full 360 degrees.

Latitude	Date	Time	Post Height h in mm	Shadow Length s in mm	Air Mass	Degrees Phi	Degrees Sun Alt	Calculated Max Curr Degrees	Julian Day	Noon Degrees Declination	Noon Degrees Alt
-34	[illegible]	1:20 PM	1005	1370	1.690642	53.7371	36.2629	126.2629	220.00	15.964136	139.9641

Angle	Current	0.57*cos(angle -125 degrees)
0	0.06	-0.33
10	0.07	-0.24
20	0.08	-0.15
30	0.09	-0.05
40	0.09	0.05
50	0.12	0.15
60	0.23	0.24
70	0.34	0.33
80	0.43	0.40
90	0.5	0.47
100	0.54	0.52
110	0.56	0.55
120	0.57	0.57
130	0.56	0.57
140	0.55	0.55
150	0.52	0.52
160	0.47	0.47
170	0.41	0.40
180	0.33	0.33
190	0.26	0.24
200	0.16	0.15
210	0.09	0.05
220	0.05	-0.05
230	0.06	-0.15
240	0.06	-0.24
250	0.05	-0.33
260	0.05	-0.40
270	0.05	-0.47
280	0.05	-0.52
290	0.05	-0.55
300	0.05	-0.57
310	0.05	-0.57
320	0.05	-0.55
330	0.05	-0.52
340	0.05	-0.47
350	0.06	-0.40





Note: The explanations and methods for the additional entries of Air Mass and various angles in the above spreadsheet are available at the web site http://www.greenhouseschools.pv.unsw.edu.au

Method 2 The Line of Best Fit

Using the set up from Method 1: Position the solar module normal to the sunrays (have this be the zero for the angle measurements). Take short-circuit current measurement a 10 degree intervals until the solar module is side-on to the sunrays (at 90 degrees from the starting angle).

Create a table of Angle between Incident Ray and Normal (at 10 degree intervals) and Current. Then transform the data into another table of Cosine of Angle between Incident Ray and Normal vs Current and graph this relation.

Draw a line of best fit. A straight line indicates that the current (and therefore the illumination) is directly proportional to the cosine of angle between incident ray and the normal.

This proportionality concept is similar to the work students do with electric motors: Torque = $BIAn\cos(\theta)$ where θ is the angle between the plane of the coil and the magnetic field.

Angle of incidence	Current (A)	Angle in radians	Current	Cosine of Angle of Incidence
0.00	0.57	0.00	0.57	1.00
10.00	0.56	0.17	0.56	0.98
20.00	0.54	0.35	0.54	0.94
30.00	0.50	0.52	0.50	0.87
40.00	0.43	0.70	0.43	0.77
50.00	0.34	0.87	0.34	0.64
60.00	0.23	1.05	0.23	0.50
70.00	0.12	1.22	0.12	0.34
80.00	0.09	1.40	0.09	0.17