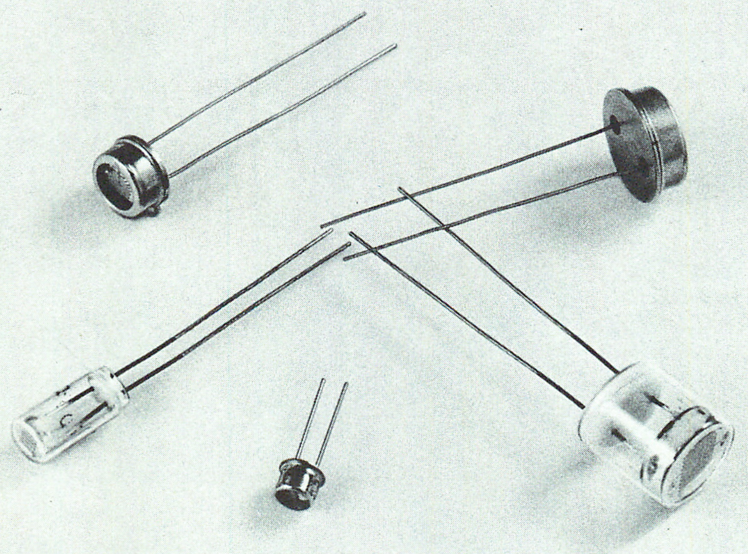
Photoconductive cell application design handbook.



CLAIREX ELECTRONICS

THE DESIGN ENGINEER will find this publication a useful guide in situations involving light control. Over seventy different types of photoconductive cells, the industry's most complete line, are described with extensive physical and electrical data given for each in both graphical and tabulated forms.

A selection of typical circuit diagrams will also offer some assistance. Although these standard cell types are calculated to suit most needs, special units are developed on request; feel free to consult Clairex or its representatives whenever your particular requirements dictate.

CLAIREX has considered the research, development and manufacture of high quality CdS and CdSe photoconductive cells its sole basis of operation for the last decade. The corporation acquired the title of oldest manufacturer of these cell types as a birthright; its industry-wide reputation as the prime producer of reliable light-sensitive components, however, has been earned through efficient, creative service to the country's leading companies. Clairex invites you to its facilities the next time you visit New York.

If a special photocell is required, Clairex has over seventeen years experience designing cells to customer specifications. These have involved many variations on standard cells in Clairex' hermetically sealed packages. Extensive modifications of cells to obtain a desired conductance at a particular light level, unusual voltage ratings, and special sensitive area configurations have also been accomplished.

In some special cases it became necessary to modify the spectral response of the cells to suit a particular design situation. This involved the development of a modified photoconductive material.

Where special cells may be required, consultation is always advisable prior to submission of a detailed cell design for quotation. Such consultation will help assure that the design is within the state of the art.

Occasionally component parts and tooling will exist which are adaptable to a particular special requirement. However, the design engineer would serve his purposes best by attempting to use standard cells wherever possible and thus avoid the delay and expense necessarily involved in any special manufacturing operation.

CONTENTS

IMPORTANT

Specific cell data on individual types is on separate, loose leaf sheets that are included with this design manual.

PHOTOCELL DESIGN, THEORY AND APPLICATION

This section will describe the basic operation of photoconductive cells and provide a step by step objective outline of the design considerations in selecting the appropriate cell for a specific application. Every effort is made to define the terms and discuss the theory used so that the designer will be able to extract technical data provided in this manual and accompanying data and apply this information in specifying a photoconductive cell.

THEORY AND OPERATION OF PHOTOCONDUCTORS

Photosensors

Today there are (4) basic types of photosensors in use. Photo emissive, photovoltaic, photoconductive junction type and photoconductive bulk effect. The purpose of this manual is to discuss primarily the CdS and CdSe bulk effect photoconductors.

The photo emissive type measures light by the emission in a vacuum of one electron per photon impinging on a metal photo cathode. Photo multipliers having successive stages using secondary emissions are used to amplify the electron current.

The photovoltaic type generates a voltage across a pn junction as a function of the photons impinging on it. This class is usually made of Selenium or Silicon and is the only self-generating type, thus requiring no external power supply.

Photo diodes and photo transistors represent the "junction type" photoconductors. The resistance across the semiconductor junction changes as a function of light falling on it. They are very fast in response but limited in sensitivity due to the small area of the junction.

Photoconductive cells bulk effect are normally made of Cadmium Sulfide (CdS) or Cadmium Selenide (CdSe). Unlike the junction types, they have no junction. The entire layer of material changes in resistance when it is illuminated. In this respect it is analogus to a thermistor except the heat is replaced by light. The photoconductive cell decreases in resistance as the light level increases and increases in resistance as the light level decreases. The absolute value of resistance of a particular cell at a specific light level depends on the photosensitive material being used, cell size, electrode geometry, and on the spectral composition of the incident light.

Although photoconductors require an

Photocell Design, Theory and Application

external power supply, a sensitivity 1000 times greater than the photovoltaic class more than compensates in most applications. The photoconductor's sensitivity to steady light is 1,000,000 times that of the photo emissive type and equal to that of the photomultiplier, without the burdensome necessity of a high voltage power supply required by the latter. Photo diodes and transistors have faster response times than CdS and CdSe photoconductive cells but their poor sensitivity to light limits their use to those applications where relatively high illumination is available.

Cadmium sulfide (CdS) and cadmium selenide (CdSe) are the two materials most widely used in photoconductive cells. Clairex specializes in the manufacture of photoconductive cells using CdS and CdSe as the base materials. From these two compounds Clairex has developed a number of materials in order to provide the best possible characteristics for a wide variety of applications.

Design Criteria For Selection of Photoconductive Cells

The selection of a photocell for a specific application requires the determination of two distinct groups of parameters. The first of these will allow the designer to choose the exact photoconductive material which is best suited for his application. The second group of parameters will allow for the determination of the physical configuration of the photocell. Clairex offers (7) varieties of CdS and CdSe materials and five different cell configurations. In addition, Clairex provides a wide choice of power and resistance ratings.

SELECTION OF PHOTOCONDUCTIVE MATERIAL

Spectral Response

The relative sensitivity of a photoconductive cell is dependent on the wavelength of the incident light.

Each photoconductive material has a unique response curve which indicates the portion of the light spectrum it is sensitive to. Figure 1 and Figure 2 are typical spectral response curves for two Clairex materials.

From these curves it can be seen that material 2 has its peak spectral response at 5150 Angstroms and material 3 at 7350

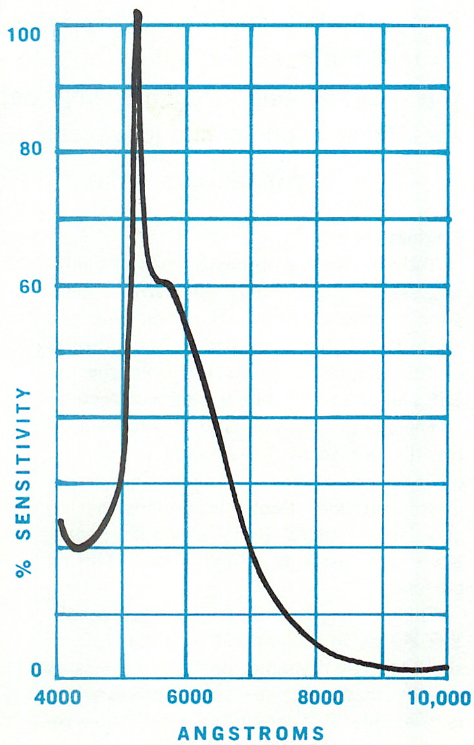


Figure 1

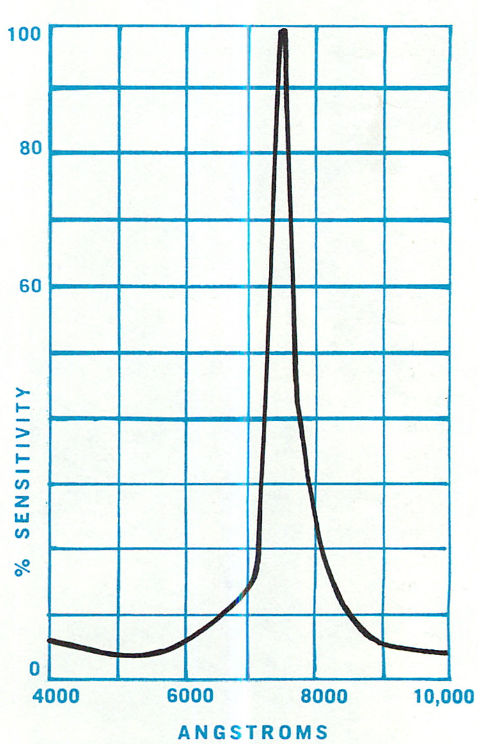


Figure 2

Angstroms. This indicates that material 2 is most sensitive to light in the blue-green spectrum and material 3 is most sensitive to light in the red near IR region.

In designing it is important to choose a photoconductive material and/or light source which will provide maximum relative sensitivity. Relative sensitivity is the ratio of cell conductance at the light wavelength being employed to the cell conductance that would be obtainable had the wavelength of the light source used been exactly equal to the peak wavelength of the material. This is expressed in Figure 3.

Color Temperature Response

In most applications, monochromatic light sources are not used. More commonly we find incandescent, neon, or sunlight. Thus the overall response to a continuous light source becomes very important. If the photocell must operate over a varying color temperature range, a cell must be picked which is the least sensitive to varying color temperature. In other words, it should have a "flat color temperature response." On page 13 the curves illustrate this variation with the different materials. Applications that require the cell to operate in a high stray light ambient which differs in color temperature from the signal light, require cells with non flat response. An example would be a fluorescent ambient with a tungsten signal light. Here a CdSe cell solves the problem with its much higher response to the lower color temperatures of tungsten lights.

The curves also illustrate the need for close control of color temperature in all test fixtures, this can become a major source of poor correlation in testing results.

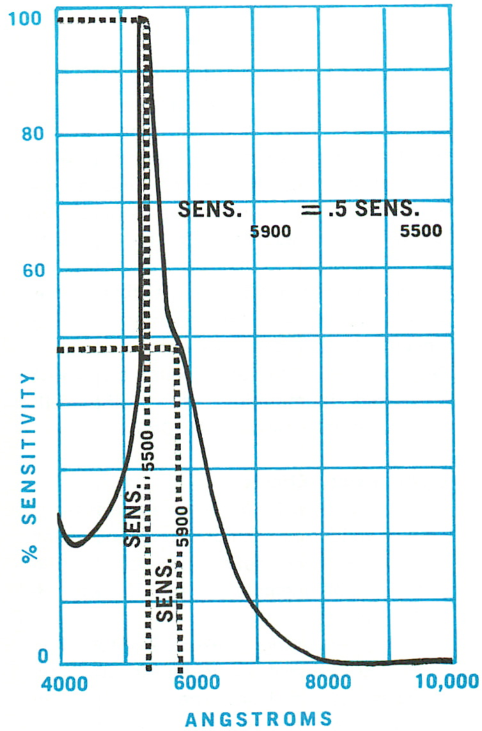


Figure 3

Sensitivity

The sensitivity of a photocell can be assessed only as related to an application and circuit.

Most broadly, cell sensitivity is the relationship between the light intensity impinging upon the sensitive area of the cell and the signal output of the cell in the circuit.

In a simple relay circuit (cell, power supply, and relay all in series), the output desired is relay current. Thus, a cell is most sensitive which for a given light level will pass the most current—the cell with lowest resistance.

Where the cell 'drives' a tube grid, the cell-circuit output desired is a voltage into an essentially open circuit. Here, a cell must be capable of withstanding a large voltage change and dissipation considerations dictate a high resistance cell.

Where the light signal input is a small change in illumination, sensitivity is primarily related to the slope of the cell resistance vs. light intensity curve.

The specific photoconductive material used will determine the resistivity, and the slope and linearity of the resistance curve. The actual resistance of a specific cell is a function of the geometry of the active area within the cell.

In choosing a photocell, the application for which the cell is to be used will determine which parameter is of prime importance. For example, where the cell is to be used in a switching application the greater the slope of the resistance characteristic (versus light level) the faster will be the switching action.

Depending on the specific material which is used the ratio of dark to light resistance varies in Clairex cells from 100:1 to 10,000 to 1. In determining the resistance ratio it is necessary to specify at what time after the light is removed the dark resistance is measured. Clairex specifies five seconds dark, after exposure to 2 ft-c.

A perfectly linear photoconductive material is one in which a given percentage change in light level will result in the same percentage change in resistance over the entire range of illumination. While no material can be perfectly linear, Clairex Type 5H material exhibits the most linear characteristic over the widest light level range.

In general, CdSe cells are super linear below 1 ft-c and become sub linear above. All CdS/CdSe photoconductors become less linear as the light level is increased, until in the 10,000 foot-candle range they are almost asymptotic.

Photocell Design, Theory and Application

Linearity of resistance with changing light levels suggests a whole family of applications in the meter and control areas.

Temperature Coefficients

The temperature coefficients of photoconductors are rather unique, as they are a function of light as well as material. CdS cells have the lowest coefficient and in general their resistance changes inversely with temperature change. CdSe cells have considerably higher coefficients and their resistance varies directly with temperature. As was stated earlier, the coefficient is also a function of light intensity. The coefficient varies as an inverse function of light level. Thus to minimize temperature problems, it is desirable to work the photocells at the highest light level practical.

Photocell Resistance

The resistance of a photocell is a function of the basic material resistivity and total active area. In general, CdSe materials are considerably lower in resistance than CdS materials when used with conventional light sources. An example would be Clairex Type 4 material which is 33 times lower in resistance than Type 2 material. The second factor is the active area of the photoconductor, which is determined by the physical size and the electrode configuration. By todays evaporation techniques it is possible to deposit electrodes in very fine patterns which allow exposure of a large area of the cell surface and very close electrode gaps. This technique allows low resistance in small size cells, however the close spacing requires lower voltage ratings. To obtain low resistance and high voltage rating, it is necessary to have a large photocell substrate with big electrode gaps.

On page 11, the basic material resistivity curves are shown with the various factors for different electrode configurations.

Speed of Response

Speed of response of a photoconductive cell is the time required for the current to increase after the cell has been illuminated (rise time) and the time required for the current to decrease (resistance increase) after light has been removed. (Decay Time). In general, in this manual, turn on time is measured from the beginning of illumination to the time it takes the current to reach 63% of its final value. Response time can be measured over any specific resistance range which is desired. All cells exhibit faster response times with increased illumination, with CdSe cells being normally faster than CdS.

Light History Effects

In common with all known light sensors, photo-conductors exhibit a phenomenon which has been called fatigue, "hysteresis," "light memory," "light history effect," etc.

The phenomenon takes the following form: the present or instantaneous conductance of a cell at a specific light level is a function of the cell's previous exposure to light and of the duration of this exposure. The magnitude of the effect depends on the present light level, on the difference between present and previous light levels, and on the durations of previous and present exposure. The sense or direction of the effect depends on whether the previous level was higher or lower than the present one.

An example will help clarify this last statement: a cell kept at the test light level will attain an equilibrium conductance. If this cell is kept at a lower light level or in total darkness for some time and then checked at the test level; its conductance will be greater (than the equilibrium value) and will decay asymptotically to the equilibrium value.

Conversely, if the cell is kept at a higher light level and then checked at the test level, initial conductance will be lower and will rise asymptotically to the equilibrium value. The higher the test level, the more rapid is the attainment of equilibrium.

The magnitude of the effect is larger for Cadmium Selenide than for Cadmium Sulphide; but the selenides tend to reach equilibrium more rapidly.

Naturally, this phenomenon must be taken into consideration in applying photoconductive cells.

The "light history effect" (preferred term) is a definite hindrance in the use of photo-conductive cells for the measurement of light levels. For the continuous measurement of light levels which may range in a random manner from darkness to very high light levels, precision is limited at any light level to the magnitude of the "light history effect" for that level.

For intermittent measurements, the effect of 'light history effect' may be virtually eliminated by keeping the cell in a constant light environment between measurements. For best results, a light level environment within the range of interest should be chosen.

Photocell Selection

Once the photoconductive material is chosen it is then necessary to choose the appropriate physical package. In selecting a physical package the designer must take into consideration not only mechanical requirements but also the electrical ratings of the cell for appropriate circuit compatibility.

Maximum Cell Voltage

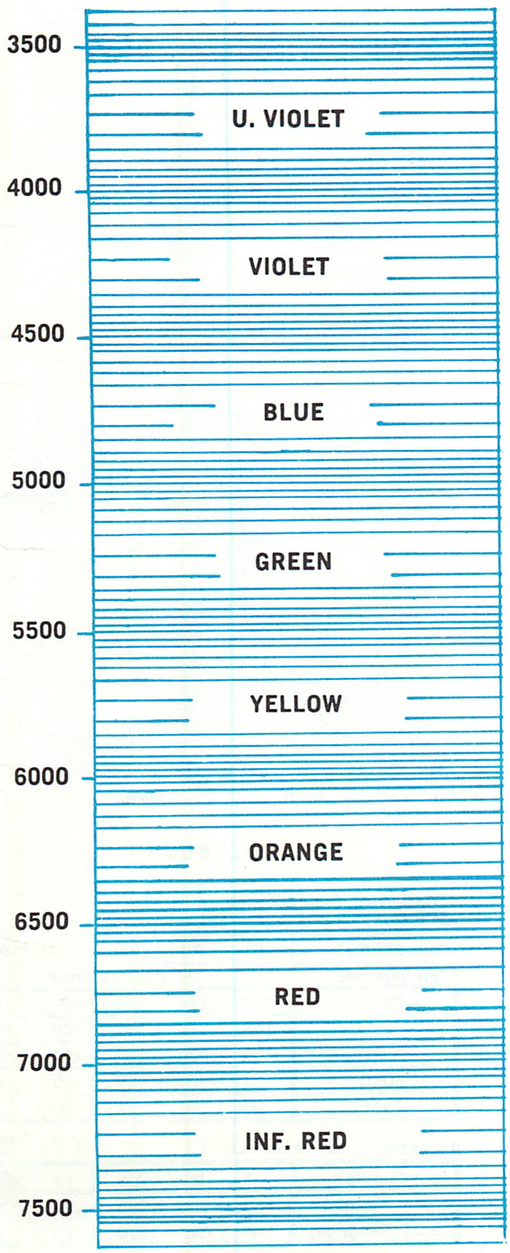
In specifying a photocell, care must be taken to insure that the voltage applied to the cell does not exceed the maximum allowable. Due to the fact that the maximum voltage is normally across a cell when it is in the dark, the voltage rating is measured with no illumination on the cell.

Summary

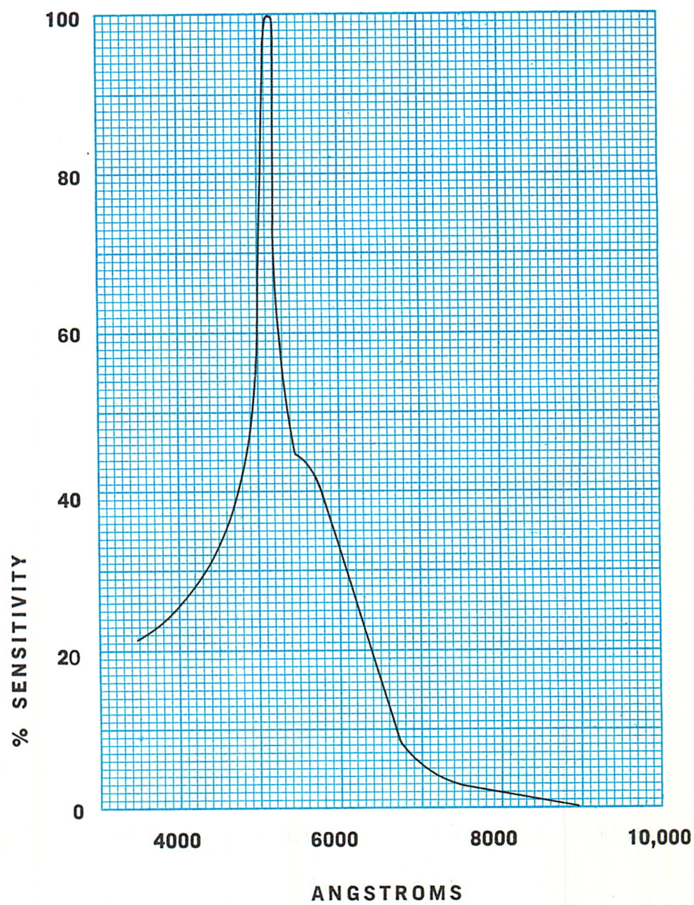
To properly select the best photocell for your application, it is important to understand the previous pages. Then examine the following charts and graphs to pick out the photocell closest to your design requirements.

PHOTOCONDUCTIVE MATERIALS

Wavelengths In Angstroms



TYPE 2 CdS, peak spectral response 5150 angstroms, bluest response photosensitive material, high stability, lowest temperature error. Can be used in applications requiring sharp differentiation in the blue green spectrum. For use with either fluorescent or incandescent lamps.



Variation of Conductance With Temperature and Light

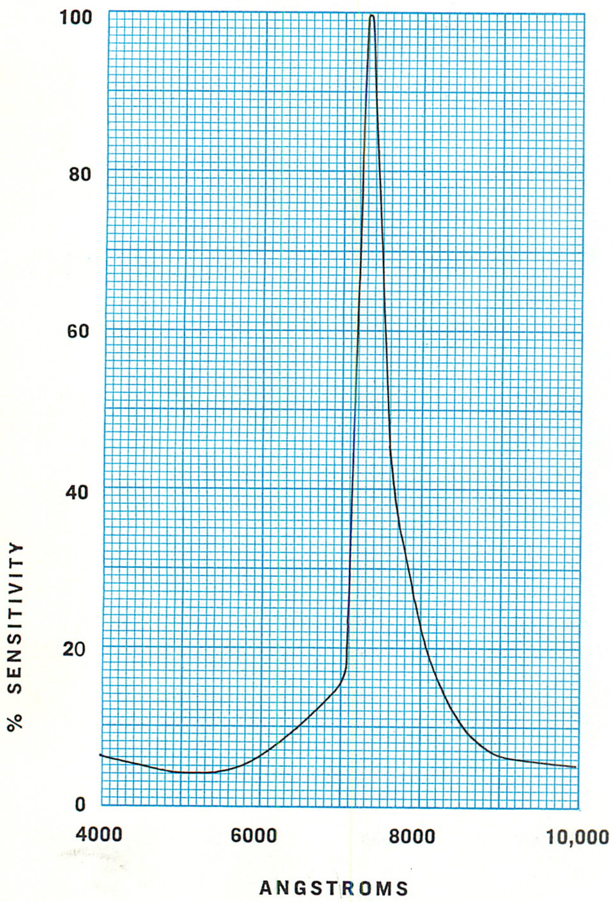
Foot Candles	.01	0.1	1.0	10	100
Temperature	% Conductance				
−25°C	85	103	106	107	107
0°C	94	100	101	102	104
25°C	100	100	100	100	100
50°C	98	96	98	97	97
75°C	86	92	98	97	96

Response Time Versus Light

Foot Candles	.01	0.1	1.0	10	100
Rise (Seconds)*	1.410	.330	.066	.017	.006
Decay (Seconds)**	.570	.085	.022	.008	.005

*Time to (1 - 1/e) of final reading after 5 seconds Dark adaption.
**Time to 1/e of initial reading.

TYPE 3 CdSe, peak spectral response 7350 angstroms, fast response, and very high light-to-dark resistance ratio. Can be used for high speed switching or counting. Sensitive to near infra red. For use with incandescent or neon lamps.



Variation of Conductance With Temperature and Light

Foot Candles	.01	0.1	1.0	10	100
Temperature	% Conductance				
−25°C	1070	320	172	116	109
0°C	500	230	140	110	108
25°C	100	100	100	100	100
50°C	43	30	57	79	87
75°C	44	20	25	42	62

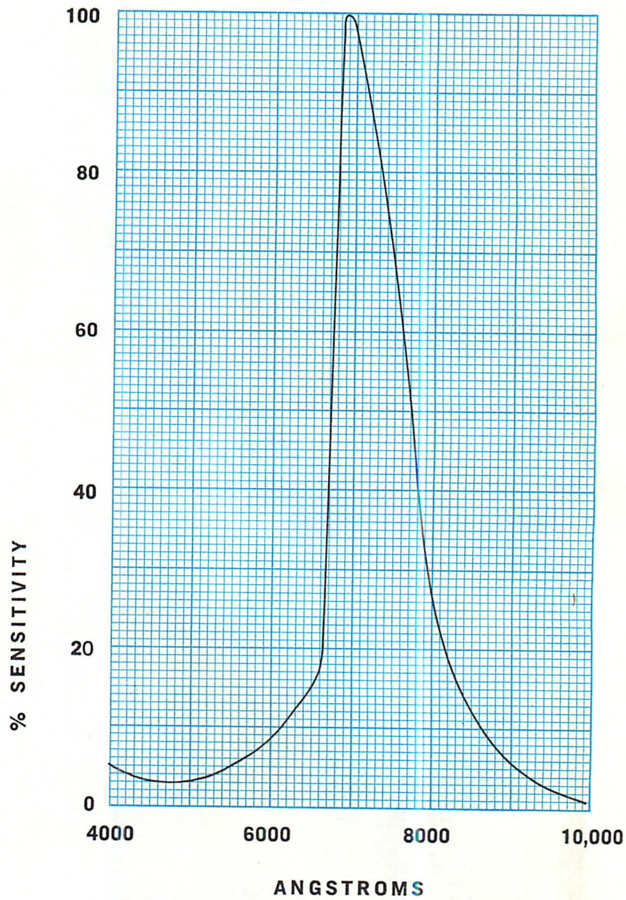
Response Time Versus Light

Foot Candles	.01	0.1	1.0	10	100
Rise (Seconds)*	.350	.070	.020	.005	.002
Decay (Seconds)**	.045	.015	.009	.006	.002

*Time to (1 - 1/e) of final reading after 5 seconds Dark adaption.

**Time to 1/e of initial reading.

TYPE 4, CdSe peak spectral response 6900 angstroms, lowest resistance photocells available. Can be used for "on-off" applications when low resistance is desired. For use with incandescent or neon lamps.



Variation of Conductance With Temperature and Light

Foot Candles	.01	0.1	1.0	10	100
Temperature	% Conductance				
−25°C	220	138	114	97	95
0°C	166	118	110	100	99
25°C	100	100	100	100	100
50°C	53	70	83	95	96
75°C	23	30	57	80	85

Response Time Versus Light

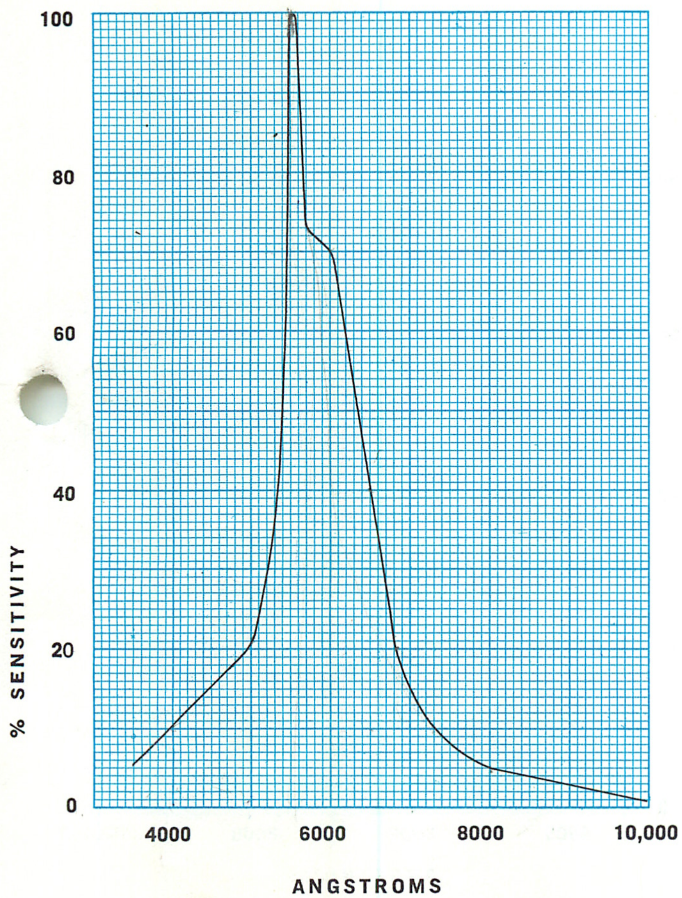
Foot Candles	.01	0.1	1.0	10	100
Rise (Seconds)*	1.780	.430	.088	.023	.005
Decay (Seconds)**	.160	.047	.030	.015	.008

*Time to (1 - 1/e) of final reading after 5 seconds Dark adaption.

**Time to 1/e of initial reading.

Includes type CL505L

TYPE 5 CdS, peak spectral response 5500 angstroms (closely matches the human eye), most stable, lowest memory photocell available. Can be used in light measuring applications and precision low speed switching. For use with incandescent, fluorescent or neon lamps.



Variation of Conductance With Temperature and Light

Foot Candles	.01	0.1	1.0	10	100
Temperature	% Conductance				
−25°C	117	108	98	95	96
0°C	105	102	96	95	97
25°C	100	100	100	100	100
50°C	96	95	101	106	104
75°C	82	81	98	111	110

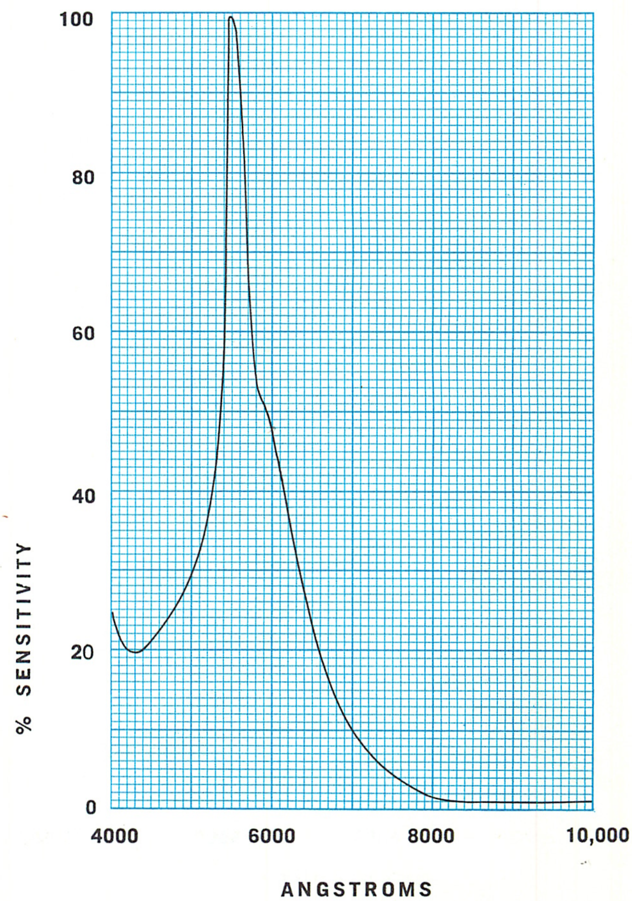
Response Time Versus Light

Foot Candles	.01	0.1	1.0	10	100
Rise (Seconds)*	5.80	.82	.140	.035	.010
Decay (Seconds)**	2.96	.56	.110	.043	.014

*Time to (1 - 1/e) of final reading after 5 seconds Dark adaption.

**Time to 1/e of initial reading.

TYPE 5H CdS, peak spectral response 5500 angstroms (closely matches the human eye). Combines high speed, stability, linearity, and uniform color temperature response. Can be used for high speed switching or high stability measuring applications. For use with incandescent, fluorescent or neon lamps.



Variation of Conductance With Temperature and Light

Foot Candles	.01	0.1	1.0	10	100
Temperature	% Conductance				
−25°C	80	85	85	88	99
0°C	93	91	91	89	98
25°C	100	100	100	100	100
50°C	93	96	105	112	109
75°C	51	81	102	120	125

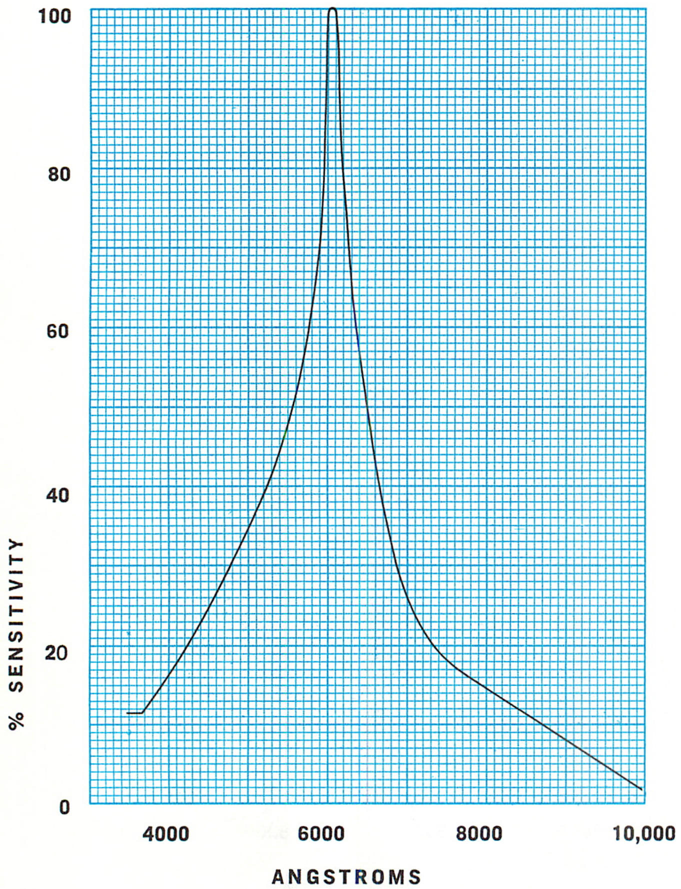
Response Time Versus Light

Foot Candles	.01	0.1	1.0	10	100
Rise (Seconds)*	1.460	.116	.030	.005	.002
Decay (Seconds)**	.159	.019	.004	.002	.001

*Time to (1 - 1/e) of final reading after 5 seconds Dark adaption.

**Time to 1/e of initial reading.

TYPE 7 CdS, peak spectral response 6150 angstroms, moderate speed and ratio. Can be used in general beam breaking applications. For use with incandescent, neon or fluorescent lamps.



Variation of Conductance
With Temperature and Light

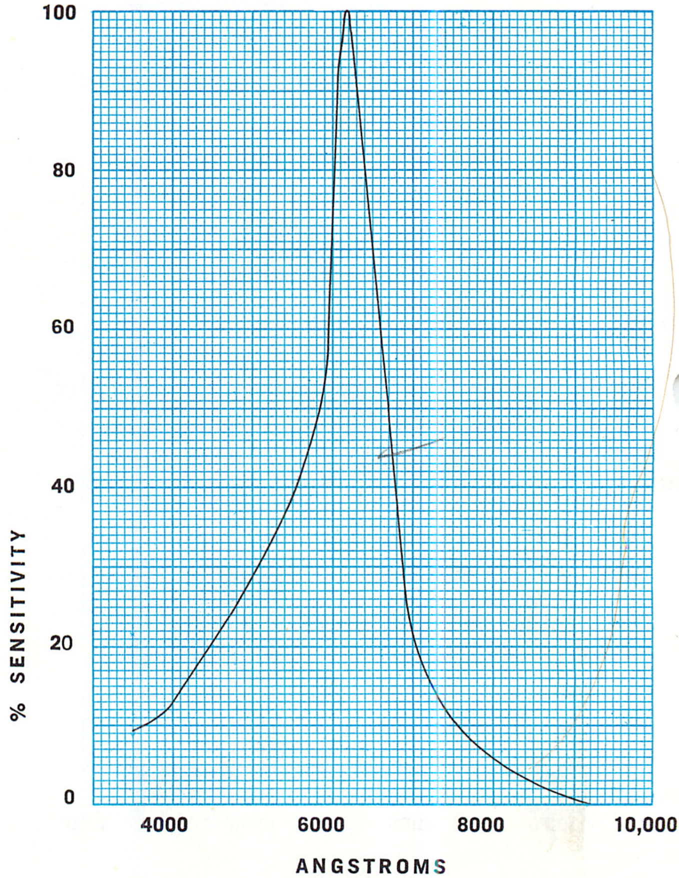
Foot Candles	.01	0.1	1.0	10	100
Temperature	% Conductance				
−25°C	114	106	98	92	91
0°C	112	110	101	97	96
25°C	100	100	100	100	100
50°C	74	84	92	96	100
75°C	37	59	72	85	90

Response Time Versus Light

Foot Candles	.01	0.1	1.0	10	100
Rise (Seconds)*	.790	.320	.088	.022	.005
Decay (Seconds)**	.520	.093	.041	.016	.007

*Time to (1 - 1/e) of final reading after 5 seconds Dark adaption.
**Time to 1/e of initial reading.

TYPE 7H CdS Peak spectral response 6200 angstroms, fast decay time combined with low resistance and high slope. Ideal for fast switching between close light levels or where temperature stability is critical.



Variation of Conductance
With Temperature and Light

Foot Candles	.01	0.1	1.0	10	100
Temperature	% Conductance				
−25°C	175	110	97	90	82
0	166	110	99	97	91
25°C	100	100	100	100	100
50°C	55	80	93	98	104
75°C	6	42	75	92	103

Response Time Versus Light

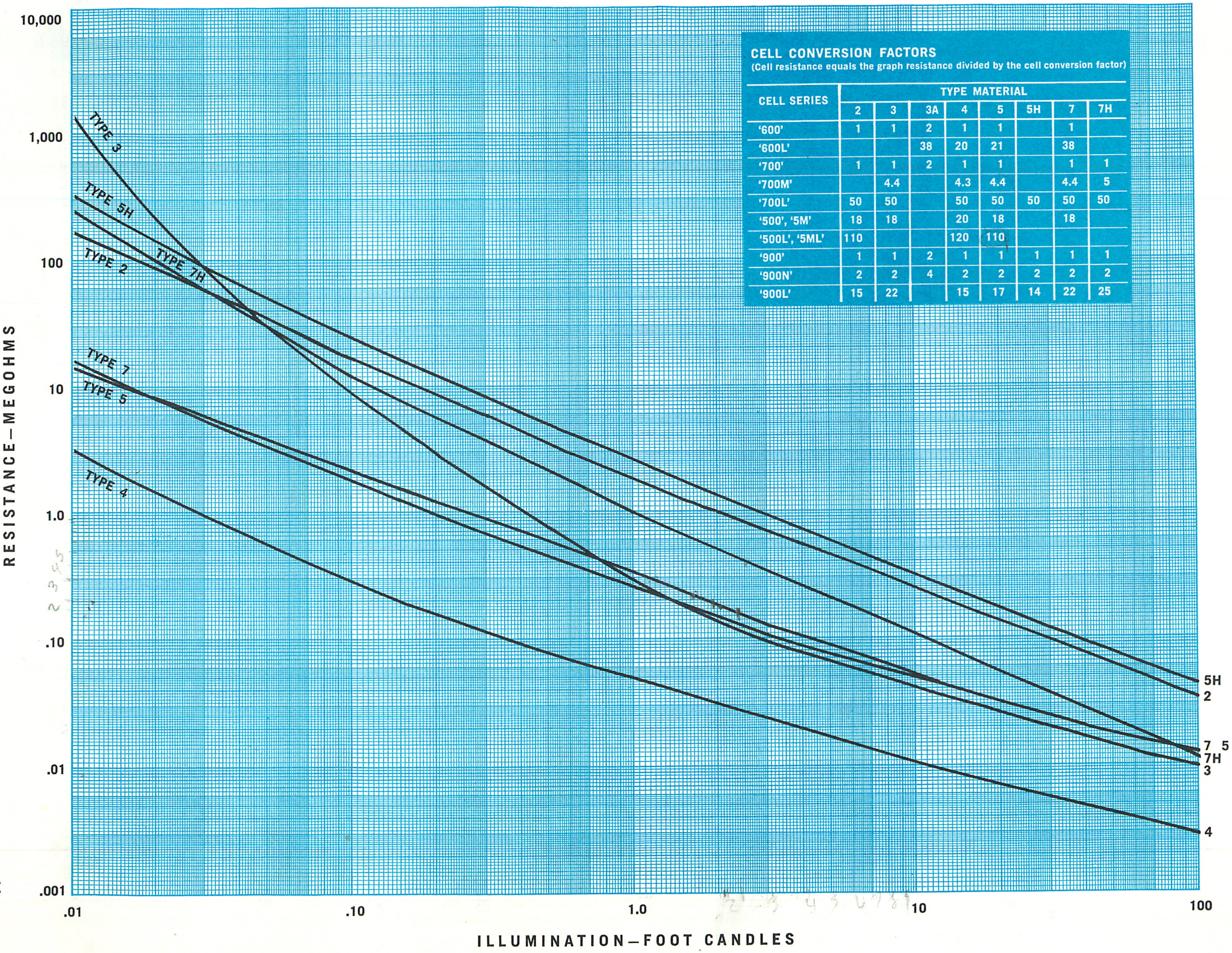
Foot Candles	.01	0.1	1.0	10	100
Rise (Seconds)*	2.51	.53	.11	.018	.004
Decay (Seconds)**	.40	.052	.006	.0015	.0006

*Time to (1 - 1/e) of final reading after 5 seconds Dark adaption.
**Time to 1/e of initial reading.

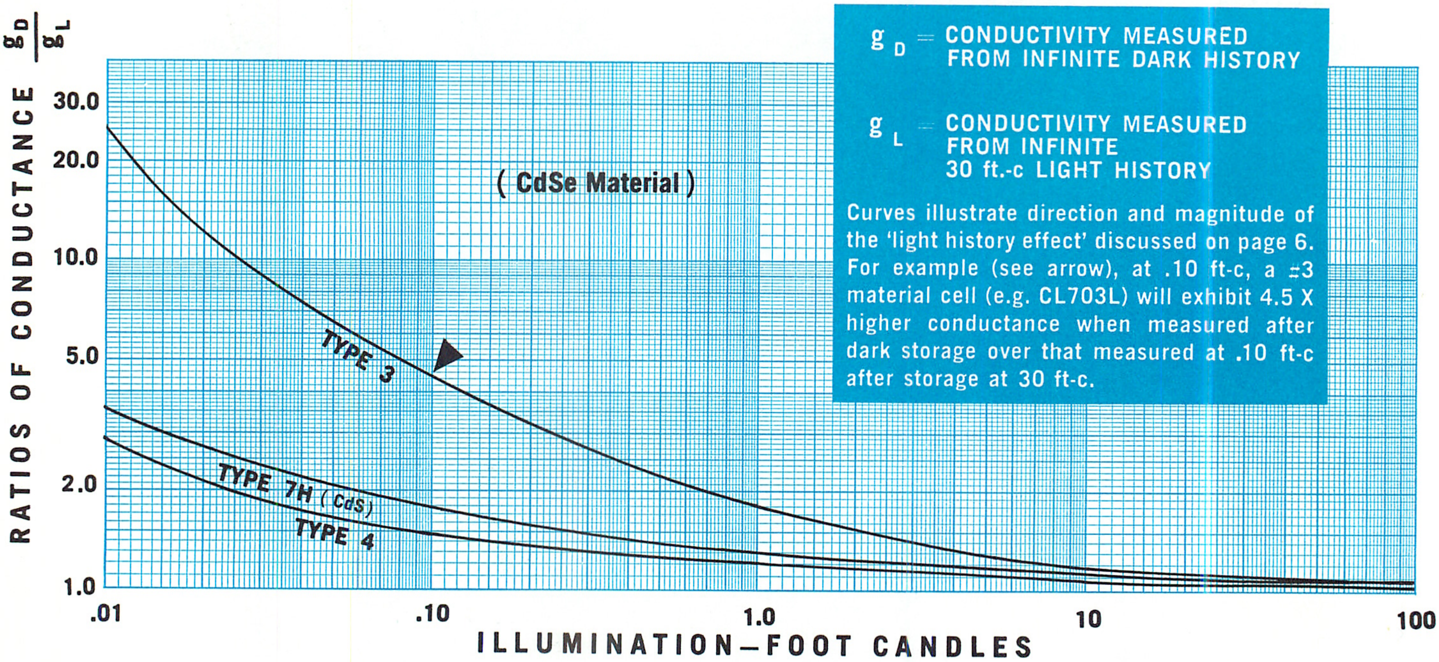
CELL RESISTANCE CURVES

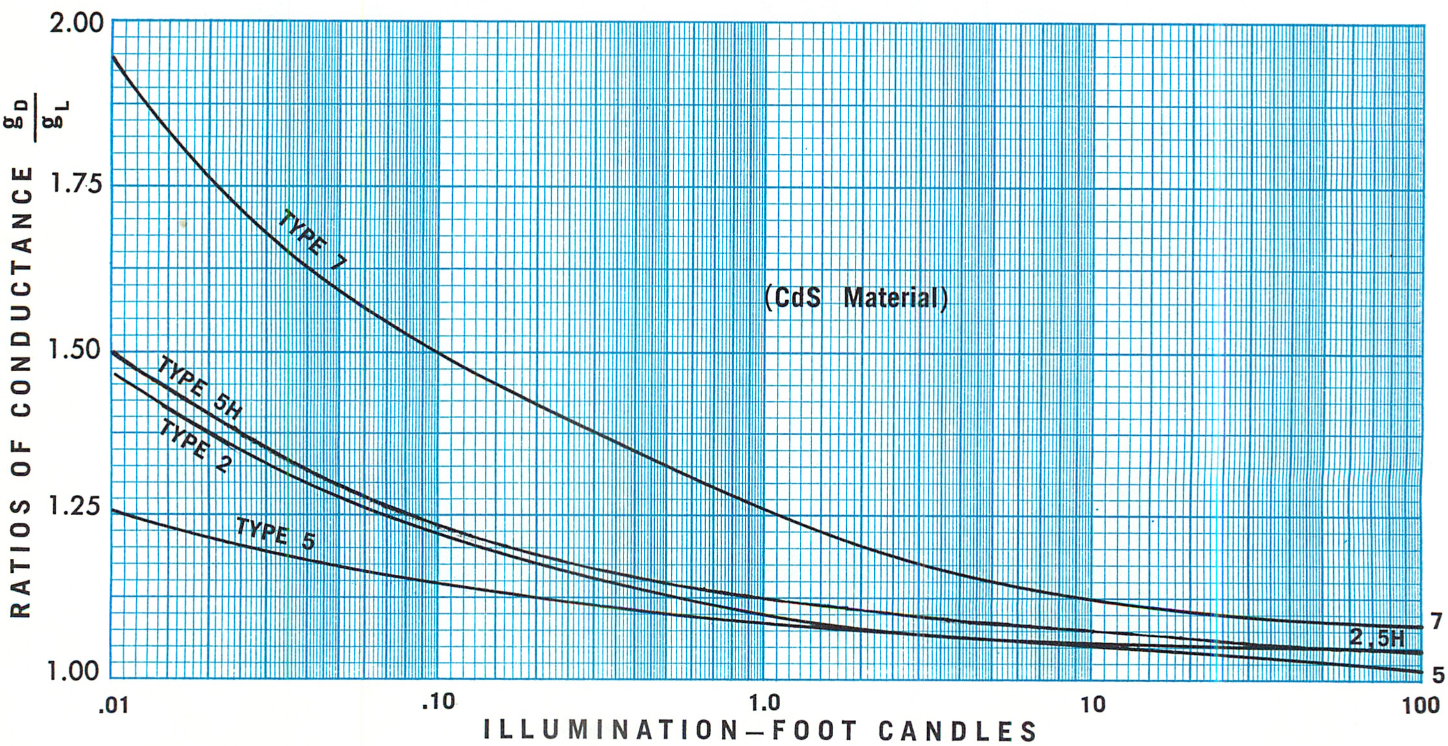
CELL CONVERSION FACTORS
(Cell resistance equals the graph resistance divided by the cell conversion factor)

CELL SERIES	TYPE MATERIAL							
	2	3	3A	4	5	5H	7	7H
'600'	1	1	2	1	1		1	
'600L'			38	20	21		38	
'700'	1	1	2	1	1		1	1
'700M'		4.4		4.3	4.4		4.4	5
'700L'	50	50		50	50	50	50	50
'500', '5M'	18	18		20	18		18	
'500L', '5ML'	110			120	110			
'900'	1	1	2	1	1	1	1	1
'900N'	2	2	4	2	2	2	2	2
'900L'	15	22		15	17	14	22	25



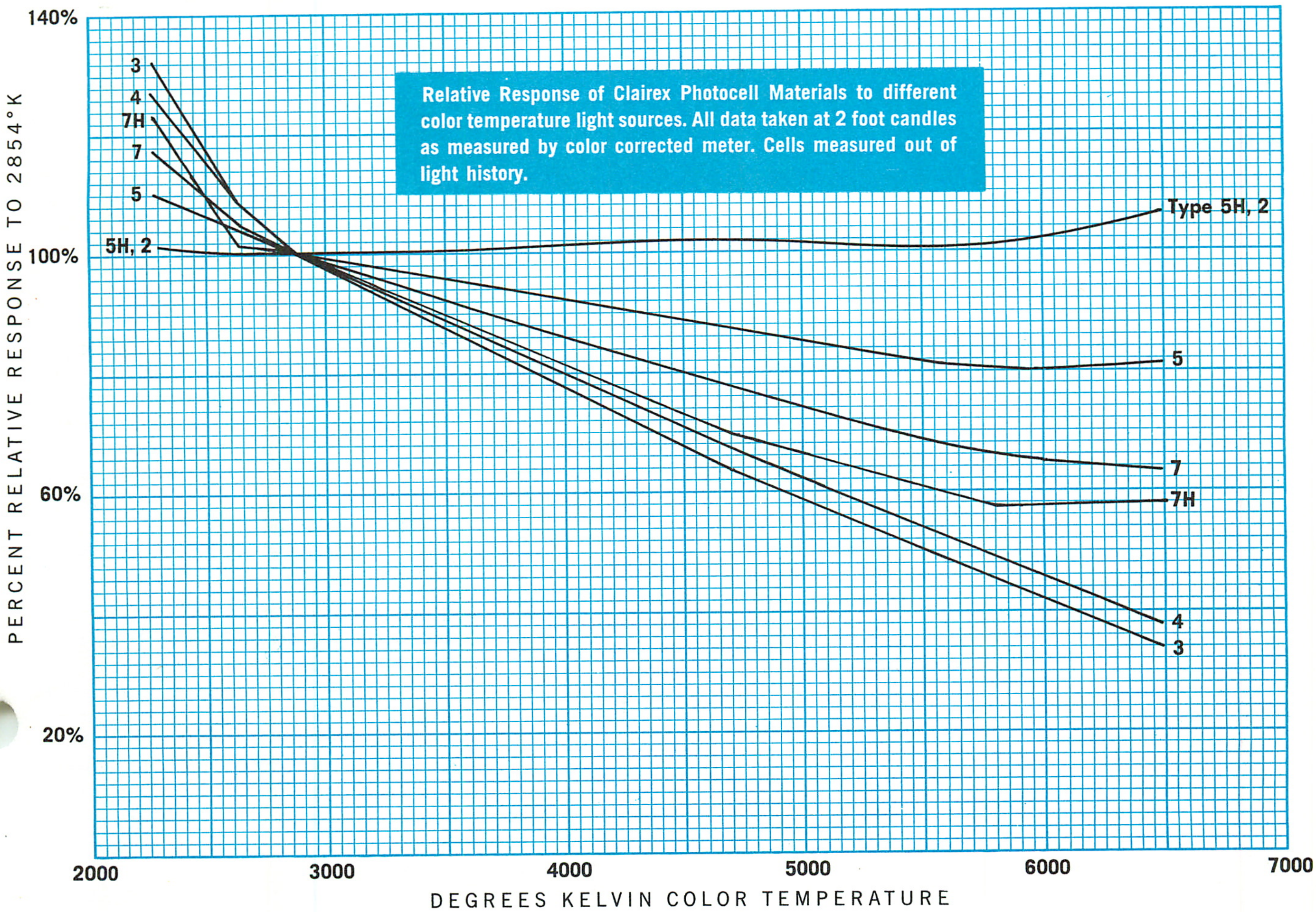
VARIATION OF CONDUCTANCE WITH LIGHT HISTORY



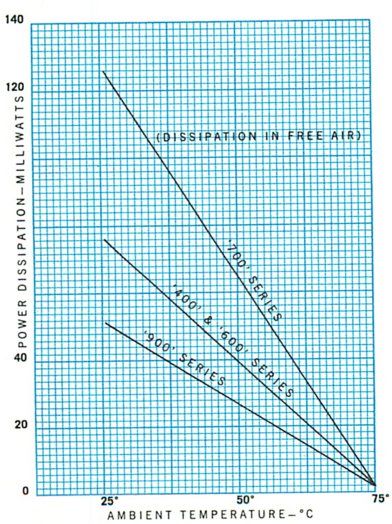


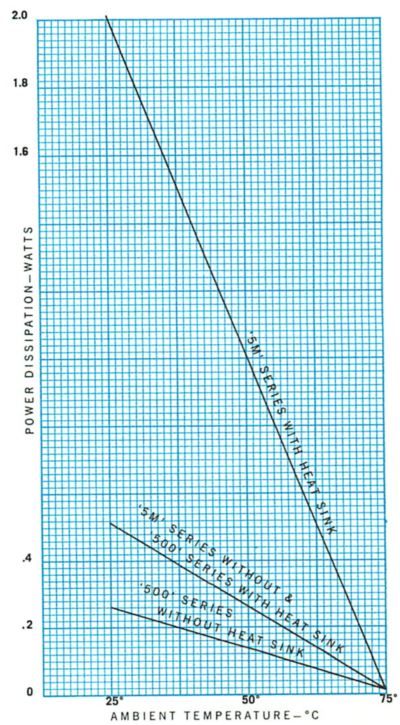
COLOR TEMPERATURE AND POWER DERATING CURVES

COLOR TEMPERATURE RESPONSE



POWER DERATING CURVES





LIGHT MEASUREMENT, A DISCUSSION

Photometry is a difficult field of precise measurement. The original standard for candle power was a candle of special construction which was observed by the human eye as it burned and then compared to the unknown source. Thus the spectral quality of the light and the sensitivity of the sensor were extremely difficult to reproduce accurately. Today a special lamp has replaced this candle as the primary reference and the human eye has been replaced by thermopiles with filters to simulate eye sensitivity. However, even with these improvements, light measurements remain difficult to reproduce due to stray light effects, color temperature shifts, nonuniform light distribution, drift of sensors, and other circumstances.

In all photometric operations it is necessary for the lamps to be at a known color temperature. Since tungsten lamps have a continuous spectral output their spectral characteristics must be defined in terms of color temperature. For normal work, standard lamps are run at a color temperature of 2854°K.

The secondary standards used today are tungsten lamps which have been carefully measured for their candlepower output at a controlled voltage and current. These standards are available from the National Bureau of Standards as well as several private testing laboratories. Their output is expressed in HCP or Horizontal Candle Power. Output is normally measured in a plane perpendicular to the lamp's vertical axis at a height in line with the filament. Usually the lamp is also marked as to the front and rear sides. With this calibration it is possible to reproduce a variety of illumination levels, by just varying the distance between the photocell and lamp. The foot candles falling on the photocell will equal the HCP of the lamp divided by the square of the distance between them.

$$\frac{HCP}{D^2} = \text{Foot Candles}$$

Whenever possible, it is most desirable to make all light measurements in terms of foot candles as the most easily reproduced unit of light. Whenever foot candle measurements are made, it is important to keep the lamp as far away from the sensor as possible to enable it to act as a point source. A good rule of thumb: maintain a distance of at least six times the longest source dimension.

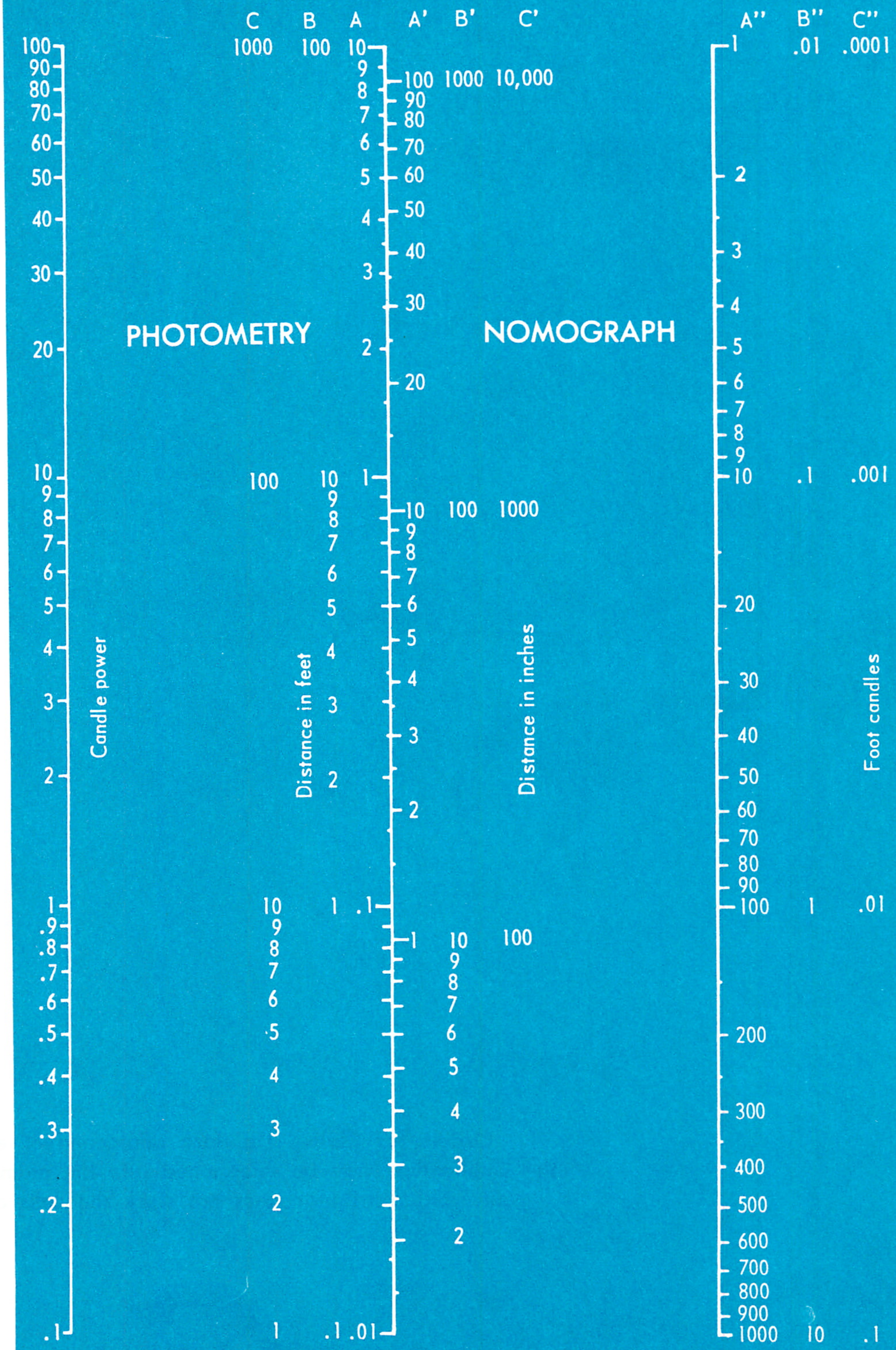
There are occasions when foot candle measurements are not applicable and brightness measurements are required. For example, if light is reflected from a secondary surface, causing it to be not a point source but an area source. The common unit used to express brightness is the foot lambert. A foot lambert is the brightness of a uniformly diffusing surface reflecting 100% of the light falling on it when illuminated with one foot candle. Therefore, if one foot candle illuminated a surface which had a reflectance of 80%, the brightness of the surface would be .8 foot lambert.

A frequent method of simulating brightness sources is to place a sheet of opal glass between the photocell and lamp. This glass is available calibrated for a conversion factor of foot lamberts on one side of the glass per foot candle illuminating the opposite side.

The nomograph to the right solves the light intensity equation noted previously for both feet and inches. Results are obtained on similar sets of scales, that is, either use all A scales for a calculation, or use the B or C scales as required by the quantities being calculated. *For instance*, a 20 candlepower lamp is 5 ft. from a photocell. What is the light intensity at the photocell? A line drawn from 20 on the Candlepower scale through the Distance scale, opposite 5 on scale B, intersects the Distance scale opposite 0.80 on the B scale.

PHOTOMETRY, NOMOGRAPH

(Read correspondingly headed columns, i.e., A, A', A'', etc.)



Unfortunately, most lamps are classified according to wattage rather than candlepower. The following approximate relationships are useful:

1. Depending upon the application for which they are designed, lamps are rated for lifetimes of seconds to near infinite life. The shorter the rated life, the higher the efficiency (cp/w) and the higher the color temperature of the light.

2. If we restrict ourselves to standard voltage (120v) inside-frosted incandescent lamps rated for 1000 hours, we find that:

- Efficiency increases with increasing wattage.
- A 25w lamp is near 19 cp, a 60w lamp near 60 cp and a 150w lamp is near 200 cp.
- Color temperature increases with increasing wattage.
- Color temperature of a 150w lamp is near 2900 Kelvin.
- Light output varies at approximately the 3½ power of the supply voltage (near rated voltage).
- Lamp life is approximately proportional inversely to the 13th power of the supply voltage (near rated voltage).
- When lamps are operated at constant voltage, light output falls with time, rapidly during the first 50 hours, more slowly thereafter (this is the reason for aging photometer lamps).
- When lamps are operated at constant current, light output rises with time, slowly at first, then accelerating to catastrophic destruction.

A sample line drawn to the right for a 6 candle power lamp shows that at 2.94″ or .245′ from the lamp filament we have an intensity of 100 foot candles. Similarly, at 29.4″ the intensity is 1 foot candle and at 294″, .01 foot candle.

Several useful definitions:

A Foot Candle is the illumination produced when the light from one candle falls normally on a surface at a distance of one foot.

A Lux (commonly used in Europe) is the illumination produced when the light from one candle falls normally on a surface at a distance of one meter.

A point source emiting light uniformly in all directions radiates 4π lumens/candle.

A lambert is the brightness of a perfectly diffusing surface emittting or reflecting one lumen per square centimeter.

A Foot Lambert equals $1/\pi$ candles/sq. ft.

To order photoconductive cells or obtain technical information, contact the Clairex Corporation directly or your nearest Clairex representative.

Orders for Clairex standard photoconductive cells listed in this publication may be telephoned into the main office if your local distributor does not stock the cells of your choice.

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