May 13, 1941. J. T. NICHOLS 2,241,557

PHOTOMETRIC APPARATUS

Filed July 25, 1936 2 Sheets-Sheet 1

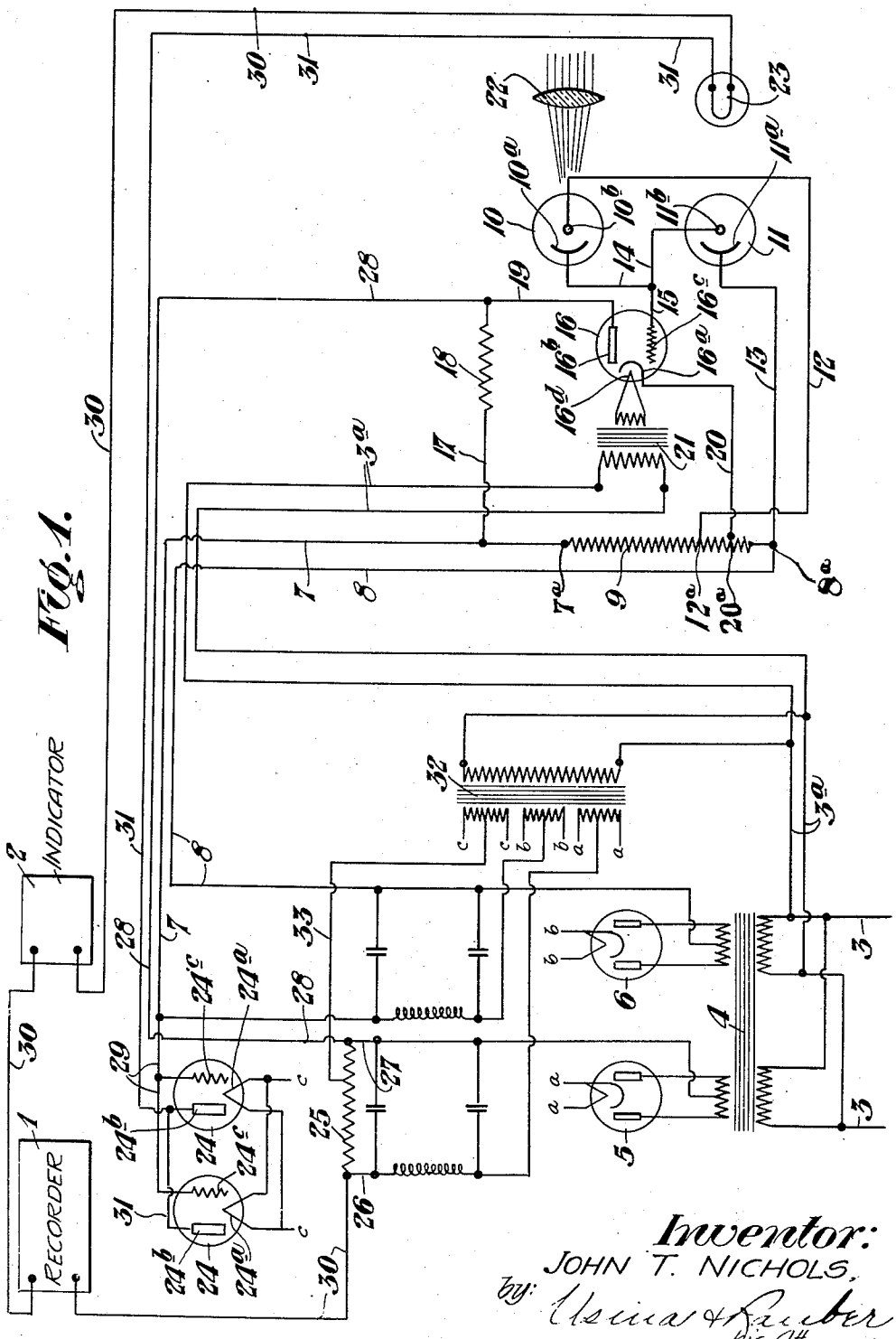


Fig. 1.

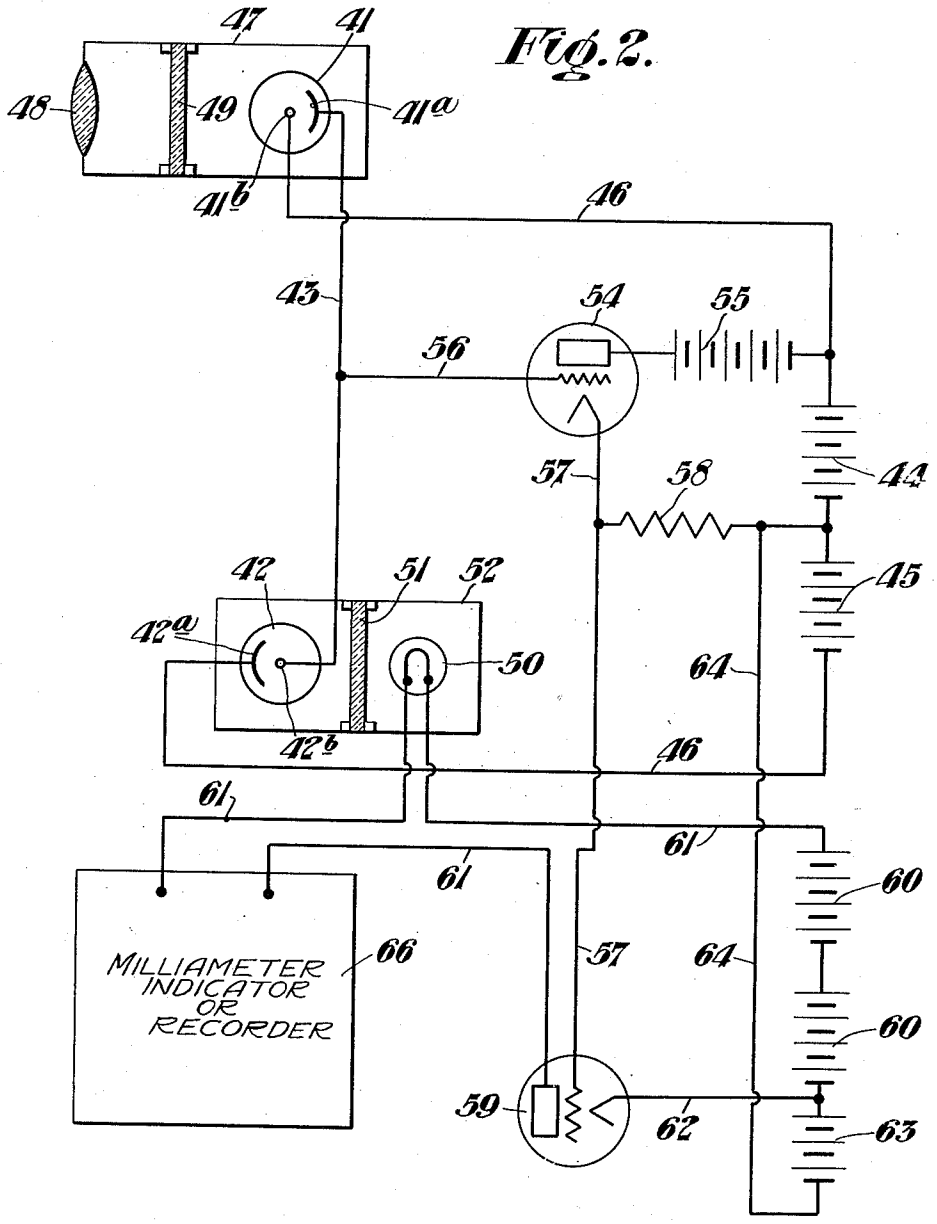
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PHOTOMETRIC APPARATUS

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Fig. 2.



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UNITED STATES PATENT OFFICE

2,241,557

PHOTOMETRIC APPARATUS

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14 Claims. (Cl. 88—23)

This invention relates to photometric apparatus and the like, and is a continuation-in-part of my co-pending application entitled "Photometry," bearing Serial #680,887 and filed July 17, 1933; one of my objects being to provide a photometer which operates through the medium of photoelectric cells in such manner as to provide more accurate results than were hitherto obtainable. Other objects may be inferred from the following disclosure of specific examples of my invention.

In the accompanying drawings, Figure 1 schematically illustrates my invention in the form I now consider preferable, and Figure 2 schematically shows another example.

The preferred form includes a milliameter recorder 1 and a milliameter indicator 2, which are shown as separate units although they may be combined into one or either used to the exclusion of the other. Alternating power lines 3 energize the secondary of a transformer 4 which supplies energy to two full wave rectifiers 5 and 6 provided with the usual electric filters for producing a smooth direct current. The rectifier 6 supplies energy through conductors 7 and 8 to a voltage divider or resistance 9.

This voltage divider provides an electric energizing means for two similar photoelectric cells 10 and 11 respectively having electron-emissive photocathodes 10^a and 11^a and anodes 10^b and 11^b. The anode 10^b of the cell 10 and the photocathode 11^a of the cell 11 are connected through conductors 12 and 13 to the resistance or energizing means 9, while the anode 11^b of the cell 11 is connected to the photocathode 10^a of the cell 10 by a conductor 14, the conductor 13 connecting with the negative end of the resistance 9 and the conductor 12 connecting with the resistance 9 at a point positive to the negative end of the latter. This point is chosen so as to provide the voltage required to properly energize the cells 10 and 11. It is to be here noted that the two cells are connected in series and are energized by the same source of electric current, this being an important feature of the invention to be subsequently explained.

Specifically referring to the voltage divider 9, the line 7 carrying positive current connects with this divider at the point 7^a, and the line 8 carrying negative current connects with the divider at the point 8^a. The line 12 connects with the divider 9 at the point 12^a and the line 13 connects at the point 8^a, the line 20 connecting at the point 20^a which is between the points 8^a and 12^a. In this manner the results described by the above paragraph are secured.

A conductor 15 connects the conductor 14 to the control grid of an electronic valve 16, the latter including an electron-emissive cathode 16^a, an anode 16^b and the grid 16^c to which the conductor 15 connects. The anode 16^b is connected to the positive end of the resistance 9 by a conductor 17, resistance 18 and conductor 19, while the cathode 16^a of the valve 16 is connected by the conductor 20 to the resistance 9 at a point between the conductors 12 and 13. The cathode 16^a of the valve 16 is provided with a heater element 16^d powered by a separate transformer 21 having its primary connected to the power lines 3 by lines 3^a.

The photocathode 10^a of the cell 10 is adapted to receive light to be measured by way of a focusing lens 22, and an electric lamp 23 is arranged to illuminate the photocathode 11^a of the cell 11.

A pair of electronic valves 24, which also function as amplifiers, are provided. Each has a cathode 24^a, an anode 24^b and a control grid 24^c. A resistance 25 is electrically energized by the rectifier 5 through conductors 26 and 27 which connect with the ends of this resistance. The negative end of this resistance 25 is connected by a conductor 28 to the negative end of the resistance 18, the positive end of the latter being connected to the grids of the valves 24 by way of a conductor 29 which connects with the conductor 7. A conductor 30 connects one end of the filament of the lamp 23 with the positive end of the resistance 25 through the recorder 1 and indicator 2, and a conductor 31 connects the other end of this filament with the anodes 24^b of the valves 24. The cathodes 24^a of the valves 24 are heated by being connected to the windings *c—c* of a transformer 32, the center point of these windings being connected by a conductor 33 to a suitable point on the resistance 25.

This transformer 32 is part of the rectifying equipment, the details of the latter not being more specifically given because they are not considered material at the present time. It also provides windings *a—a* and *b—b* which heat the cathodes of the rectifiers 5 and 6.

Operation of the invention in this preferred form is as follows:

Electrons are emitted or liberated from the photocathode 10^a of the photoelectric cell 10 when this photocathode receives light by way of the lens 22. As previously explained, this is the

light to be measured. This causes the control grid 16c of the electronic valve 16 to become more positive whereby this valve passes more current from its cathode 16a to its anode 16b, this correspondingly increasing the potential drop in the resistance 18. Since the potential drop in this resistance 18 controls the potential of the control grids 24c of the electronic valves 24, the current from the cathodes 24a to the anodes 24b of these valves is increased. This increases the current through the lamp 23, and since this lamp illuminates the photocathode 11a of the cell 11 the emission or liberation of electrons from this photocathode increases. This increase of electrons from the photocathode 11a tends to make the control grid 16c of the valve 16 less positive.

It is apparent that the current through the lamp 23 will increase until the illumination from this source is sufficient to liberate the same quantity of electrons from the photocathode 11a of the cell 11 as are liberated from the photocathode 10a of the cell 10. Since this condition is dependent on the photocathode 11a being illuminated to the same extent as the photocathode 10a, it is possible to measure the light focused by the lens 22 by reading the current through the lamp 23, this being the function of the milliameter recorder 1 and indicator 2. These two instruments may, of course, be calibrated to read in any manner desired. That is to say, if the light focused by the lens 22 is being measured to determine its illuminating power the calibrations may be in foot candles, whereas when temperature determination is desired the calibrations may be in degrees Fahrenheit or centigrade.

One of the features of this preferred form is the fact that voltage fluctuations do not materially affect the results obtained. In commercial work voltage fluctuations in the power lines are to be expected, and any apparatus powered by these lines is consequently subjected to these fluctuations. Due to the previously described arrangement of the photoelectric cells and their connection to the power lines by way of the voltage divider, both cells are subjected to voltage fluctuations at the same time so that their effects are nullified. In other words, since it is the relative conductivities of the two cells which are involved and since the relationship prevails when the fluctuations are the same in the case of each cell, accurate readings result at all times.

It is also to be noted that fluctuations in the voltage applied to the electronic valves and the lamp illuminating the photoelectric cell balancing the photoelectric cell receiving the light to be measured, cannot materially affect the results obtained. In making this statement it is assumed that the voltage will never reach a point where the capacity of the various elements is exceeded, nor diminish so that it is inadequate to meet the demands of these elements. Obviously, in the case of such extreme fluctuations no apparatus can operate.

Theoretically, the bridge circuit network including the photocells 10 and 11 in two adjacent arms, and including the portions of the voltage divider between the points 12a and 20a, and 20a and 8a, respectively, in its other two arms, can be in stable and exact balance for only one degree of illumination of the cell 10. For that degree of illumination, the equilibrium current flow through the lamp 23 may be that resulting from the potential of the grid 16c which is established when the illumination of the cell 11 is exactly equal to the illumination of the cell 10. For all other degrees of illumination of the cell 10, the relative illuminations of the two cells 10 and 11 must differ when the potential of the grid 16c is that required to make the current through the lamp 23 that required to bring the system into equilibrium. With photoelectric cells 10 and 11 of the electron-emissive type described, however, as those skilled in the art will recognize, the extent to which the illumination of the cell 11 must differ from that of the cell 10 for different degrees of illumination of the latter, in order that the system may be brought into equilibrium is practically insignificant, and in all equilibrium conditions the said bridge circuit network is thus substantially balanced.

In Figure 2, two photoelectric cells 41 and 42 are connected in series by a line 43 and to batteries 44 and 45, also connected in series, by lines 46. It is to be noted that these cells are illustrated as being of the electron-emissive type. The cell 41 is enclosed by a casing 47 and receives its light through a lens 48 and screen 49, it being understood that this light is that which is to be measured. The cell 42 is provided with an illuminating lamp 50 whose light must pass through a screen 51, these elements being shielded against extraneous light by a casing 52. This lamp is, in effect, a variable illuminating means.

A 3-element electronic valve 54 has its anode connected to the positive side of the battery 44 through a battery 55 in series therewith. Its grid is connected to the line 43 between the two cells by a line 56. The valve's cathode is connected between the batteries 44 and 45 through a line 57 and resistance 58.

A second 3-element electronic valve 59 is arranged with its grid connected to the line 57. The lamp 50 is energized through this valve 59, which functions as an electrical valve as well as an amplifier, by batteries 60 and lines 61 and 62, the former connecting to the anode and the latter to the cathode of the valve 59. A battery 63 is in series with the batteries 60 and connects through a line 64 to the battery end of the resistance 58. A milliameter indicator or recorder 66 is arranged in series with the lamp 50 to measure the energy used thereby. This instrument may be replaced by a contacting device if the apparatus is to effect some control, or other changes made to suit particular uses.

The operation of the apparatus is as follows:

The cell 41 becomes conductive when it receives light focused on it by the lens 48 and this makes the grid of the valve 54 more positive, causing an increase in the current passing through it and a consequent potential drop in the resistance 58. Therefore, the grid of the valve 59 becomes more positive and consequently causes a greater amount of current to flow through the lamp 50. As this lamp brightens, the cell 42 becomes conductive and makes the grid of the valve 54 less positive, and as this valve controls the grid of the valve 59 the latter is also made less positive. Obviously, a balanced condition results, which is dependent on the relative conductivities of the two cells, the energy used by the lamp 50 then being an indication of the value of the light being received by the cell 41. The milliameter 66 indicates or records this measurement and the readings obtained may be converted into units of light measurement.

If the light falling on the cell 41 comes from hot metal, the milliameter readings may be calculated to produce temperature readings direct-

ly. In the case of color or shades, the instrument may be calibrated accordingly.

The screens 49 and 51 may be used for various purposes. One of these may be to assure proper "black body" corrections, as the screens may be colored to transmit monochromatic red light only, the Bureau of Standards having already made accurate corrections of this character for this color so that it is not necessary for the user to do so. In any event, the corrections for red light, as applied to pyrometric methods of obtaining the true temperature of steel in the open, are relatively small as compared to those for other colors. Therefore, red screens are desirable when the apparatus is to be used as an automatic optical pyrometer.

In the example disclosed by Figure 2, screens are shown in front of the photoelectric cells. In addition to passing only monochromatic light these screens may function to control or regulate the conductivities of the two photoelectric cells, it being understood that these cells as commercially manufactured may not possess the same characteristics.

Furthermore, it is to be understood that the photoelectric cells 41 and 42 are each provided with an electron-emissive photocathode and anode. The electronic valves described obviously may be of the same character described in the preferred form of the invention. In all cases the photoelectric cells are to be distinguished from selenium cells, photovoltaic cells or any other form of light responsive element not providing electron-emissive photocathodes.

I claim:

1. The combination of two photoelectric cells each having an electron-emissive photocathode and an anode, an electronic valve having an electron-emissive cathode, an anode and a control grid, means for electrically interconnecting the anode of one of said cells and the photocathode of the other, means for electrically connecting the grid of said valve between said anode and said photocathode of said cells, electric energizing means, an electric resistance, means for electrically connecting said resistance to said energizing means so as to establish an electric circuit through the former, means for electrically connecting the other anode and the other photocathode of said cells to said resistance at such points as to negatively energize the photocathodes of said cells, means for electrically connecting the cathode of said valve to said resistance between the connections of said other anode and said other photocathode therewith, illuminating means for the photocathode of one of said cells, the photocathode of the other of said cells being arranged to receive light from another source, an electrically operated control means having no physically moving parts for said illuminating means, electric energizing means for said control means, means in circuit with the anode and cathode of said valve for controlling said control means, and means for measuring the extent said control means is operated.

2. The combination of two photoelectric cells each having an electron-emissive photocathode and an anode, an electronic valve having an electron-emissive cathode, an anode and a control grid, means for electrically interconnecting the anode of one of said cells and the photocathode of the other, means for electrically connecting the grid of said valve between said anode and said photocathode of said cells, electric energizing means, means for electrically connecting the other anode and the other photocathode of said cells to said energizing means so their photocathodes are negatively energized, means for connecting the cathode of said valve to said energizing means so that current from the latter is divided thereby, an electric lamp arranged to illuminate the photocathode of one of said cells, the photocathode of the other of said cells being arranged to receive light from another source, a second electronic valve providing an electron-emissive cathode, an anode and a control grid, electric energizing means for said lamp, means for electrically connecting said lamp to the second named energizing means through the cathode and anode of the second named valve, a third electric energizing means, means for electrically connecting the cathode and grid of the second named valve to the third named energizing means through the cathode and anode of the first named valve and means for measuring the current provided said lamp.

3. The combination of two photoelectric cells each having an electron-emissive photocathode and an anode, an electronic valve having an electronic-emissive cathode, an anode and a control grid, means for electrically interconnecting the anode of one of said cells and the photocathode of the other, means for electrically connecting the grid of said valve between said anode and said photocathode of said cells, electric energizing means, an electric resistance, means for electrically connecting said resistance to said energizing means so as to establish an electric circuit through the former, means for electrically connecting the other anode and the other photocathode of said cell to said resistance at such points as to negatively energize the photocathodes of said cells, means for electrically connecting the cathode of said valve to said resistance between the connections of said other anode and said other photocathode therewith, an electric lamp arranged to illuminate the photocathode of one of said cells, the photocathode of the other of said cells being arranged to receive light from another source; a second electronic valve providing an electron-emissive cathode, an anode and a control grid, electric energizing means for said lamp, means for electrically connecting said lamp to the second named energizing means through the cathode and anode of the second named valve, a third electric energizing means, means for electrically connecting the cathode and grid of the second named valve to the third named energizing means through the cathode and anode of the first named valve, and means for measuring the current provided said lamp.

4. Photometric apparatus including the combination of two photoelectric cells of the electron-emissive type electrically connected with a source of electric energy so as to form a normally balanced electric circuit, one of said cells being arranged to receive light from an external source, an electric lamp connected with a source of electric energy and arranged to act as the sole source of illumination for the other of said cells, an electronic valve arranged in circuit with said lamp so as to control the energy supplied to the same, means in said normally balanced circuit which is responsive to any current flow in the same to automatically cause said valve to change the energy supplied said lamp so as to restore said circuit to its normally balanced con-

dition and means for measuring the electric energy supplied said lamp.

5. Photometric apparatus including the combination of two photoelectric cells connected in series, one of said cells being arranged to receive light and the other being provided with an illuminating lamp, a plurality of current sources arranged in series to energize said cells, a three-element electronic valve having its grid controlled by the current between said cells and current sources, a current source for said lamp, a three-element electronic valve in series with said lamp and having its grid controlled by the output of the first named valve and means for measuring the current passing through said lamp.

6. Photometric apparatus including the combination of two photoelectric units of the electron-emissive type electrically connected with a source of electric energy, one of said units being arranged to receive light from an external source, an electric lamp connected with a source of electric energy and arranged to act as the sole source of illumination for the other of said cells, an electronic valve arranged in circuit with said lamp so as to control the energy supplied to the same, means connected in a circuit with said photoelectric units and said source of energy which is responsive to the relative conductivities of the two photoelectric units, which means is active upon change in the relative conductivities of said units caused by a change in the relative amounts of light received by said units to cause said valve to change the energy supplied to said lamp to substantially restore the relation between the amounts of light received by said two cells existing before said change, and means for measuring the electric energy supplied said lamp.

7. Photometric apparatus including the combination of two photoelectric units of the electron-emissive type electrically connected with a source of electrical energy, one of said units being arranged to receive light from an external source, a second source of light, arranged to act as the sole source of illumination of the other of said units, solely electrical means including an electrical circuit for controlling the amount of illumination supplied by said second source of light to said last mentioned photoelectric unit, said circuit including energizing means and an electronic valve for controlling the flow of energy through said circuit, means connected in a circuit with said photoelectric units and said source of electrical energy which is responsive to the relative conductivities of the two photoelectric units, which means is active upon a change in the relative conductivities of said units, caused by a change in the relative amounts of light received by said units, to cause said valve to change the energy supplied to the circuit controlling the amount of illumination supplied by said second source of light to its associated photoelectric unit to substantially restore the relation between the amounts of light received by said two cells existing before said change, and means for measuring the energy supplied to said circuit.

8. In combination, a first light-operated variable resistance device adapted to be subjected to a source of light, an electrical valve including grid means, connections between said first light-operated variable resistance device and the grid means of said electrical valve to vary the bias on the grid means, a second light-operated variable resistance device, solely electrical means to vary the light to which said second light-operated variable resistance is subjected, connections between said electrical means and electrical valve, connections between the second light-operated variable resistance device and the grid means of the electrical valve to vary the bias on said grid means in a direction opposite to which it is varied by said first light-operated variable resistance device, and a device responsive to the resulting flow of current to said electrical means.

9. In combination, a first photoelectric cell adapted to be subjected to a variable light, a second photoelectric cell, an electric lamp to illuminate said second photoelectric cell, a thermionic device including a plate, a filament and grid means, a circuit for said lamp controlled by the plate and filament of said thermionic device, connections between said photoelectric cells and grid means by which said photoelectric cells tend to bias said grid means in opposite directions to conjointly control the flow of current to said lamp and a device responsive to the flow of current to said lamp.

10. In combination, a first photoelectric cell of the electron-emissive type subject to light of unknown value, a second photoelectric cell of the electron-emissive type, means having no mechanically movable parts including an electrical circuit to vary the value of light to which said second photoelectric cell is subjected, current flow controlling means in control of the current flow in said circuit, connections between the first photoelectric cell and said current flow controlling means to increase the flow of current through said circuit upon an increase in the value of said unknown light, connections between said second photoelectric cell and said current flow controlling means to decrease the flow of current through said circuit upon an increase in the value of the light to which the second photoelectric cell is subjected, whereby both of said photoelectric cells control the flow of current through said circuit by operating upon a single current flow controlling means so that variations in the operation of the current flow controlling means will be at least partially compensated for, and a current responsive device connected to said circuit.

11. Self balancing apparatus for measuring the magnitude of a variable condition including the combination of an electronic amplifier having an input circuit and an output circuit, a source of energizing voltage, a bridge network receiving energizing current from said source and having its equalizing terminals connected to the input circuit of said amplifier, means included in one arm of said network adapted to change in impedance in accordance with variations in said condition, adjustable means in an opposed arm of said network adapted to be varied for bridge rebalancing purposes, and physically stationary means disposed in the output circuit of said amplifier adapted to control said adjustable means.

12. Self balancing apparatus for measuring the magnitude of a variable condition including the combination of an electronic amplifier having an input circuit and an output circuit, a source of energizing voltage, a bridge network having a pair of energizing terminals and a pair of equalizing terminals, means connecting said energizing terminals to said source of voltage, means connected to said equalizing terminals adapted to control the input circuit of said amplifier, means included in one arm of said network adapted to change in impedance in accordance with variations in said condition, adjustable means in an

opposed arm of said network adapted to be varied for bridge rebalancing purposes, and physically stationary means disposed in the output circuit of said amplifier adapted to control said adjustable means.

13. Self balancing apparatus for measuring the magnitude of a variable condition including a network including physically stationary means responsive to the magnitude of said condition and adapted to be unbalanced upon change in said condition from a predetermined value, electronic amplifying means having an input circuit and having an output circuit and responsive to unbalance of said network, and physically stationary means disposed in the output circuit of said amplifier and adapted to rebalance said network.

14. In combination a photoelectric cell exposed to a variable source of light, a second photoelectric cell, a bridge circuit including said cells and having equalizing terminals and adapted to be unbalanced by a variation in the relative illumination of said cells, an electric lamp illuminating said second cell, an electronic amplifier having an input circuit connected to said equalizing terminals, and having an output circuit including a source of current and said lamp, and means for measuring the current flow through said lamp.

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