

[54] **PARALLEL ENTRY DETECTOR SYSTEM**

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Related U.S. Application Data

[63] Continuation of Ser. No. 119,802, March 1, 1971, abandoned.

[52] U.S. Cl. **250/305, 250/283, 250/397**

[51] Int. Cl. **G01t 1/36**

[58] Field of Search. **250/283, 299, 305, 250/311, 369, 397**

[56] **References Cited**

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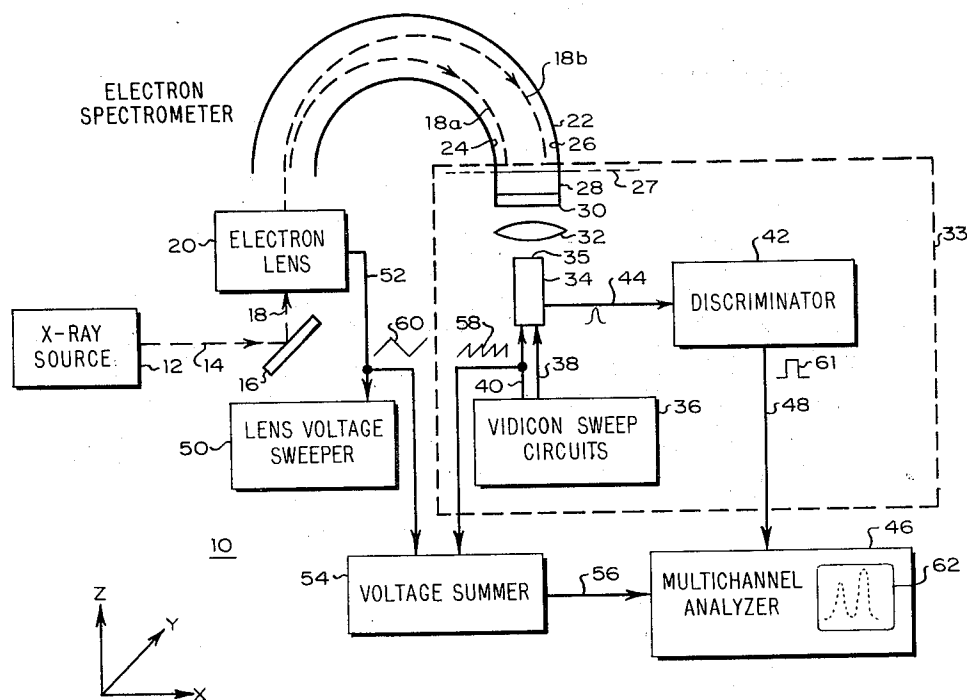
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[57]

ABSTRACT

An imaging electron multiplier, a phosphor screen, and a vidicon camera tube are employed as a multi-channel electron detector array at the output of an electron spectrometer. A sweep generator connected to an electron lens at the input of the spectrometer retards the incoming electrons in a controlled manner so that the electron energy spectrum is swept across the face of the imaging electron multiplier and, thus, across the face of the vidicon camera tube. The weighted sum of the sweep signal to the electron lens and the vertical scan signal to the vidicon camera tube is taken to provide a signal that corresponds to the original, unswept value of the energy of the electrons prior to their entering the electron lens. This signal is fed to the input of a multichannel analyzer. A pulse generated by the vidicon camera tube in response to each electron exiting the electron spectrometer causes the multichannel analyzer to sample the signal at its input. Thus, the original energy of each electron is measured and entered into the multichannel analyzer memory, regardless of where it struck the imaging electron multiplier. This eliminates distortion errors and scatter in the electron energy spectra caused by the nonrepeatability of the efficiency and noise of different detectors.

3 Claims, 3 Drawing Figures



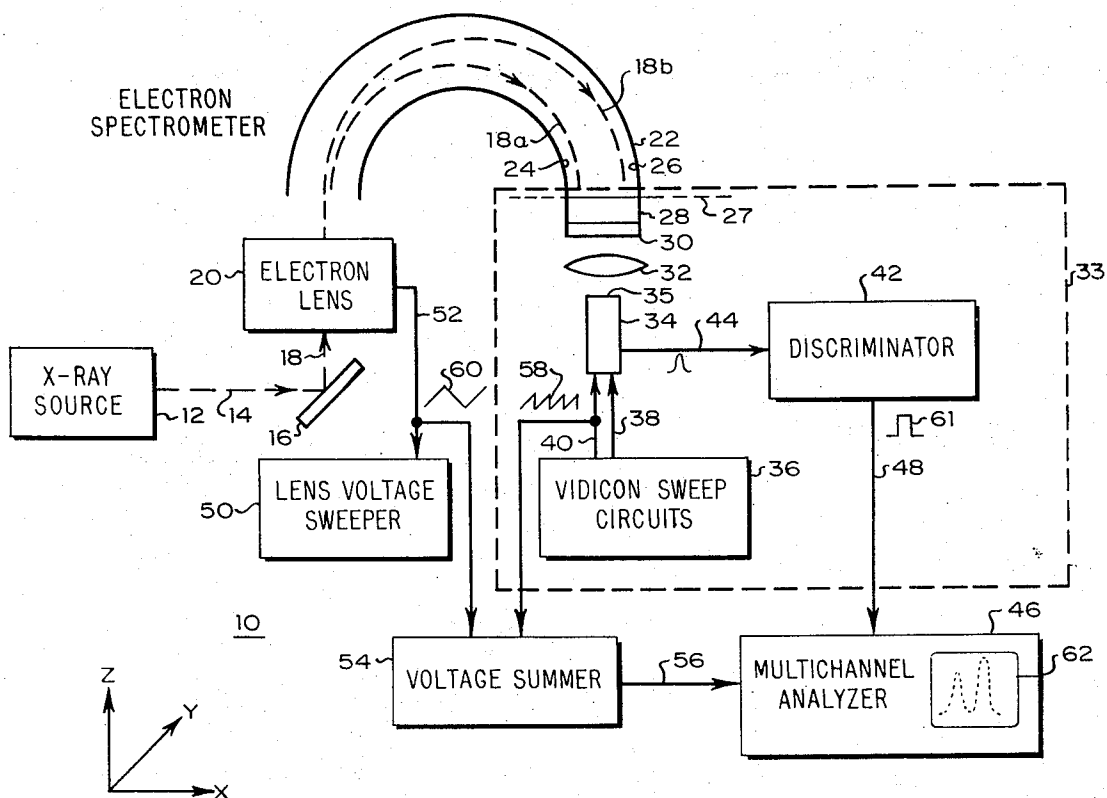
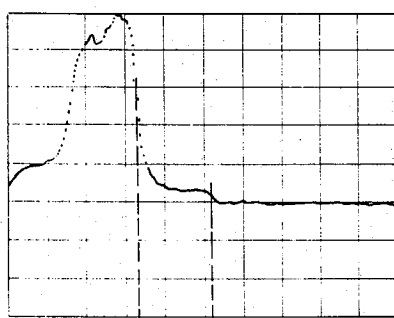
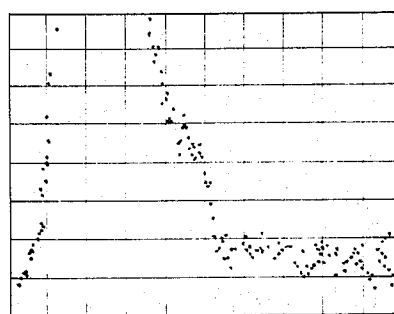


Figure 1



Ag CONDUCTION BAND
VERTICAL: 2000 COUNTS / CM
HORIZONTAL: 1.954 eV / CM

Figure 2a



EXPANDED SCALE
VERTICAL: 200 COUNTS / CM

Figure 2b

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PARALLEL ENTRY DETECTOR SYSTEM

This is a continuation of application Ser. No. 119,802, filed Mar. 1, 1971, now abandoned.

BACKGROUND AND SUMMARY OF THE INVENTION

Conventional dispersive spectrometers typically disperse a beam of particles or radiation (as used herein the word particles includes particles and radiation) to be analyzed so that it is spread across a detector region according to a selected parameter such as particle energy, momentum, mass, or wavelength. A slit allows a small segment of the spectrum to strike a detector, typically an electron multiplier. The spectrum is moved across the slit (or vice versa) in such a way that the whole spectrum can be recorded.

The particles strike the detector according to the familiar Poisson statistics. Their arrival rate is proportional to the amplitude of that segment of the spectrum entering the slit, and the signal-to-noise ratio for a given segment is equal to the square root of the number of particles detected and counted in that segment. Since the same detector senses the entire spectrum, the efficiency and noise of the detector apply equally to each segment of the spectrum.

A parallel array of detectors can accumulate a spectrum much more quickly. That is, one replaces the single slit with an array of parallel narrow detectors, each driving its own register, along the entire spectrum, so that no particles miss a detector. The spectrum is held fixed over the array, and each particle generates a count in the register connected to whichever detector that particle impinges upon. This array of detectors may be provided by employing, for example, an imaging electron multiplier, a phosphor screen, and a vidicon camera tube.

While the greater speed of the parallel detector array is a genuine advantage, this is offset by numerous problems. The noise counts, those counts which do not correspond to an incident particle, will vary for different detectors. That is, each segment of the recorded spectrum corresponding to a segment of the particle spectrum which enters a single detector of the array will have an added factor that is not correlated with the added factors of other segments. The efficiency will also vary for different detectors, so that the signal counts in each segment will be multiplied by a factor correlated with the other multiplicative factors.

These factors cause the signal-to-noise ratio of the spectrum to quickly establish a value which will not improve with the accumulation of more signal. That is, the signal-to-noise ratio of a portion of the spectrum is no longer equal to the square root of the number of accumulated counts in a typical single segment of that portion of the spectrum. Moreover, the efficiency of the detectors in the array may be weakly correlated, so that those detectors in one portion of the array are more efficient on the average than are those in some other portion of the array. This causes distortion of the spectrum. In practice, these factors usually render parallel entry detection systems completely unsatisfactory except for those rare cases when noise and detectivity are uniform across the array.

The present invention removes such efficiency and signal-to-noise ratio problems. The spectrum of particles from the dispersive region is swept across a fixed array of detectors while the array of registers, no longer

constrained to be equal to the number of detectors, is swept along with the spectrum. If the spectrum is swept from fully off one side of the detector array, across the array until fully off the other side, then each detector will contribute equally to each segment of the spectrum. That is, the contents of any given register will be the sum of the contributions of each detector. If an integral number of sweeps is performed, this is equivalent to rendering the array of detectors rigorously identical, so that Poisson statistics will apply uniformly across the entire spectrum. Since noise and efficiency are the same for each segment of the spectrum, distortion of the spectrum is removed, and the signal-to-noise ratio of a portion of the spectrum is equal to the square root of the number of counts in a typical segment of that portion.

A further advantage of the present invention is that the system can accommodate spectra of arbitrary width. If the spectrum is held fixed over an array of N detectors, then the spectrum must have N segments. In the present invention the array of detectors and the array of registers are distinct, so the spectrum can have any number of segments.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic representation of a preferred embodiment of the present invention.

FIGS. 2A and 2B illustrate results that may be obtained by using the system of FIG. 1.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. 1, there is shown an improved parallel entry detector system used as part of an Electron Spectroscopy for Chemical Analysis (ESCA) system 10. An X-ray source 12 directs a beam of X-rays 14 onto a target 16. Target 16 comprises a material to be analyzed in the ESCA system 10. X-Rays 14 eject photoelectrons 18 from the target material and the kinetic energy of one of the electrons 18 is equal to the difference of the X-ray energy and the binding energy of the state previously occupied by that electron in the target material. Thus, once the X-ray energy is known, the kinetic energy of electrons 18 may be used, for example, to identify the elements present, since the distributions of the binding energies for the electrons so ejected are unique for most elements. Electrons 18 are reduced in kinetic energy by a fixed amount and are focused into an electron spectrometer 22 by an electron lens 20. Electron spectrometer 22 separates the electrons entering it by their remaining kinetic energy. Thus, electrons 18a, which are slower than electrons 18b, exit near inner wall 24 of spectrometer 22, and electrons 18b exit near outer wall 26.

Electrons exiting spectrometer 22 impinge on an imaging electron multiplier 28, which is located at spectrometer output plane 27 and which typically has an electron gain of approximately 10^7 . The electrons exiting electron multiplier 28 in response to each impinging electron in turn impinge upon a phosphor screen 30, producing a flash or spot of light at a position on the phosphor screen corresponding to the position of the impinging electron. A lens 32 focuses the light from phosphor screen 30 onto the face 35 of a television vidicon camera tube 34. Vidicon sweep circuits 36 generate a standard television raster pattern and drive vidicon 34 through wires 38 and 40. The video output of

vidicon 34 is connected to a discriminator 42 through a wire 44, and the output of discriminator 42 is connected to a trigger input of a multichannel analyzer 46 via wire 48. Multichannel analyzers are commercially available and are described in the literature. See, for example, the *Hewlett-Packard Journal*, pp. 11-15, March 1968.

Electron lens 20 retards electrons 18 as well as focusing them, and a lens voltage sweeper 50, connected to electron lens 20 via wire 52, controls that retardation. An example of an electron lens suitable for such use is disclosed in a patent entitled ELECTRON SPECTROSCOPY SYSTEM WITH A MULTIPLE ELECTRODE ELECTRON LENS, issued on Nov. 2, 1971, to Kai M.B. Siegbahn and Edward F. Barnett, The amount of retardation applied to electrons 18 determines the lateral position of the pattern of electrons emerging from spectrometer 22 on the face of electron multiplier 28. Thus, when the voltage on wire 52 is swept between an upper and a lower limit by sweeper 50, the pattern of electrons emerging from spectrometer 22 is swept across electron multiplier 28. The pattern of light generated on phosphor screen 30 is in turn swept across vidicon face 35. The weighted algebraic sum of the vidicon vertical sweep signal on wire 40 and the electron lens sweep signal 60 on wire 52 is formed in a voltage summer 54. The output of voltage summer 54 is connected to a voltage sampling input of multichannel analyzer 46 via wire 56.

If the output of sweeper 50 is held constant, the detector system operates as follows. Electron spectrometer 22 disperses electrons 18 in the X-direction along output plane 27 according to their kinetic energy and therefore according to their binding energies in the target 16. Electron multiplier 28, phosphor screen 30 and lens 32 project a pattern of light spots onto vidicon face 35 in response to the electrons emerging from electron spectrometer 22. The vertical scan of vidicon 34 is in the X-direction and thus the vertical position (or the X-coordinate) of a given light spot is determined by the kinetic energy or binding energy of the corresponding photoelectron. Each horizontal sweep of vidicon 34 corresponds to a particular band or range of kinetic energies of electrons 18, and its vertical position is identified by a particular value of vertical sweep or scan signal 58 on wire 40. Each time a spot of light on face 35 is encountered during a horizontal sweep, an output signal appears on wire 44. That signal is shaped by a discriminator 42 into a logic pulse 61 on wire 48. Logic pulse 61 triggers multichannel analyzer 46. Multichannel analyzer 46 includes a plurality of data registers in a linear array, usually one for each horizontal sweep of vidicon 34. When multichannel analyzer 46 is triggered, it measures the value of the voltage on wire 56. This voltage is proportional to vertical sweep signal 58. Multichannel analyzer 46 then enters a count in a data register whose position in the multichannel analyzer memory is proportional to the voltage on wire 56, corresponding to the horizontal sweep then in progress. The data register so selected therefore corresponds in position to the kinetic energy of the electron which caused the light spot. Thus, each horizontal sweep of vidicon 34 acts in essence as a separate detector.

If output sweep signal 60 of sweeper 50 is now varied at a rate slower, for example, than the rate of vertical sweep signal 58, the pattern of light corresponding to electrons 18 will be swept back and forth across vid-

icon face 35. The value of sweep signal 60 corresponds to a shift in kinetic energy and therefore a shift in the position of an electron impinging upon electron multiplier 28, and vertical sweep signal 58 corresponds to the position of the impingement. The weighted algebraic sum of sweep signals 58 and 60 corresponds to the binding energy of the impinging electron. Thus, each range of electron kinetic energies will be detected in turn by each horizontal sweep of vidicon 34, but each data register of multichannel analyzer 46 will always accumulate data bits or counts corresponding to electrons in one binding energy range. That is, as the spectrum of electron binding energies is swept across electron multiplier 28, the array of data registers follows the sweep, so that each register accumulates counts from only one narrow binding energy range. Since each horizontal sweep or detector is used to detect each binding energy range, the fluctuations in noise and efficiency between the detectors (i.e., between different horizontal scans) will average out. The contents of the data registers are displayed on a display screen 62 of multichannel analyzer 46.

An excellent test of detector performance in ESCA applications is the conduction band of metals, since these signals are substantially weaker than those from deeper lying states, and since there should be only noise above the conduction band, as this region should be above the Fermi level.

FIG. 2A shows the conduction band of a Ag sample. The Fermi level E_F itself is actually resolved, as is shown in FIG. 2B, and is seen to lie 4.03 ± 0.04 eV above the half-height of the edge of the conduction band E_c .

The system background to the right or above the Fermi level is almost 6,000 counts, so one would expect, on Poisson statistics, a spread (standard deviation) of about 77 counts. The sample deviation of about 100 counts seen in FIG. 2B agrees well with this, demonstrating that the system and scheme work properly.

Although the operation of the improved parallel entry detector has been illustrated in a system acquiring one-dimensional data, i.e., only along the vidicon vertical axis, such a detector can be used for two-dimensional data also. To operate the detector in two dimensions one must sweep the image or pattern along the vertical and horizontal axes of the vidicon and must increase the number of data registers to handle the horizontal axis information. Thus, instead of entering every light spot encountered along a given horizontal sweep into one data register, each such spot would go into a separate data register. Such a detector system would be useful, for example, in transmission electron microscopy, field ion microscopy, or low light level astronomy. In the one-dimensional application illustrated with an ESCA system, it should be understood that dispersive spectrometers other than an electron spectrometer are also suitable. Also, the electron multiplier need not be of the imaging type, if only one-dimensional information is being accumulated, and the vidicon could be replaced by an array of electron detectors. For example, any of the detectors shown and described in abandoned U. S. patent application entitled PARALLEL ENTRY DETECTOR SYSTEM, Ser. No. 119,801 filed Mar. 1, 1971 by Donald L. Hammond and Hugo R. Fellner, and assigned to the same assignee as this ap-

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plication, may be employed in a system like that of FIG. 1 in place of detector 33.

We claim:

1. A dispersive spectrometer system comprising:
a source of particles;

a dispersive spectrometer having an input for receiving the particles from said source, having an output, and being operable for producing at its output a spatial spectrum of the particles as a function of a selected parameter;

parallel entry detector means having a plurality of adjacently situated elements disposed at the output of said spectrometer to receive said spatial spectrum of the particles for detecting the positions of the particles at the output of the spectrometer;

data register means, including a plurality of registers connected to said detector means, for accumulating and storing information from the detector means;

sweeping means connected to said spectrometer for sweeping the spectrum at the output of the spectrometer across said detector means; and

control means connected to said detector means, data register means and sweeping means for connecting the detector means to selected ones of the registers, each register accumulating and storing information from substantially all of the detector means elements about particles having a value of the selected parameter within a different predetermined range.

2. A dispersive spectrometer system as in claim 1 wherein:

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said particles comprise electrons;

said dispersive spectrometer comprises an electron spectrometer and an electron lens at the input of the spectrometer for focusing the electrons;

said sweeping means is connected to said electron lens; and

said control means comprises a voltage summer connected to said sweeper means, circuit means, and data register means.

3. A detector system for two dimensional data comprising:

parallel entry detector means having a plurality of adjacently situated elements for receiving and detecting the positions of particles;

data register means, including a two dimensional array of registers connected to said detector means, for accumulating and storing information from the detector means;

sweeping means for sweeping the particles across substantially all of said detector means elements in two dimensions; and

control means connected to said detector means, data register means and sweeping means for connecting the detector means to selected ones of the registers, each register accumulating and storing information from substantially all of the detector means elements about particles having positions within a different predetermined two dimensional range, uniformly averaging variations among the detector means elements over each of the registers.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,777,159 Dated December 4, 1973

Inventor(s) Donald L. Hammond and Charles E. Tyler

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 48, before "correlated" insert -- not --.

Signed and sealed this 17th day of September 1974.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents