Experiment-430 S

ARC SPECTRUM

Jeethendra Kumar P K, Ajeya Padmajeeth and Santhosh K
KamalJeeth Instrumentation & Service Unit, Tata Nagar, Bengaluru-560 092, INDIA
Email:labexperiments@kamaljeeth.net

Abstract

Using a digital constant deviation spectrometer (DCDS) and pairs of copper, brass, zinc, iron, aluminum and carbon electrodes, arc spectrum for each pair of electrodes is observed and wavelengths of prominent spectral lines in the spectrum for each of the elements are recorded and compared with the available corresponding standard spectrum. The sensitivity of the DCDS is calculated.

Introduction

Isaac Newton realized for the first time that white light consists of light of different colors (wavelengths) and using a glass prism he separated them in 1666. He first passed sunlight through a narrow slit, then through a prism, and finally the dispersed light thus obtained was projected on to a wall. This was a historic discovery that laid the foundation of spectroscopy. This effect was noticed earlier also by Descartes and others, but it was suggested that white light becomes colored when it was refracted, the color depending on the angle of refraction. Newton clarified the situation by using a second prism to reconstitute the white light from the dispersed beam, establishing the fact that white light is indeed composed of seven distinct colors. He then took a monochromatic ray from the spectrum generated by a prism and passed it through another prism, establishing the fact that no further colors are generated by the process of refraction, as was mistakenly thought earlier. He rightly concluded that white light is made up of all the colors of the rainbow, and that on passing it through a prism, these different colors are refracted at slightly different angles, thus separating them to form the observed spectrum [1].

In 1752, the Scottish physicist Thomas Melvill discovered that heating different substances in a flame and passing the light thus generated through a prism gives different patterns of spectra. Ordinary table salt, for example, generates a "bright yellow" pair of spectral lines. In addition to different rainbow colored bright lines, a few dark lines also appeared in the spectrum indicating absorption of certain wavelengths by the substances present. By 1820s it was recognized by William Herschel that spectra provide an excellent means to detect and identify even trace amounts of an element when it is powdered and heated on a flame. Meanwhile, the white light of the

sun was subjected to a detailed scrutiny by several scientists. In 1802, William Wollaston in England discovered (perhaps by using a thinner slit or a better prism) that the solar spectrum itself has several small gaps and that there are many sharp lines present in the rainbow of colors produced by the sunlight. These were investigated systematically by Joseph von Fraunhofer in 1814. He increased the dispersion by using more than one prism. He found an "almost countless number" of spectral lines. He labeled the strong ones among the dark lines as A, B, C, D, etc.
Foucault in 1849 examined the spectrum of light from a voltaic arc generated between two carbon poles. He saw a bright double yellow line at exactly the same wavelength as Fraunhofer's dark D line in the solar spectrum. Investigating this further, Foucault passed the sunlight through the arc and then through a prism. He observed that the D lines in the spectrum were even darker than usual. After experimenting with other sources, he concluded that the arc, which *emitted* light at the D line frequency, also *absorb* light from another source at the same frequency. This discovery did not surprise Sir George Stokes in Cambridge. He pointed out that any mechanical system with a natural frequency of oscillation will emit at that frequency if disturbed, but will also readily absorb at that frequency leading to the phenomenon of resonance.

The spectrum of *hydrogen*, which turned out to be crucial in providing the first insight into atomic structure over half a century later, was first observed in 1853 by Anders Angstrom in Uppsala, Sweden. His communication was translated into English in 1855. Angstrom, the son of a country minister, was a reserved person, not interested in the social life that centered on the royal court. Consequently, it took many years before his achievements were recognized, at home or abroad (most of his results were published in Swedish). Meanwhile, in Freeport, Pennsylvania in 1855, David Alter described the spectrum of hydrogen and other gases.

The first systematic investigation of spectra was by Bunsen and Kirchhoff in Heidelberg during 1855- 1863 using several techniques. They heated various salts on a Bunsen burner flame. This was an effective way of viewing spectra, because the Bunsen burner flame itself does not produce any light. They also used the cooler flame produced by burning alcohol- water mixture that generates vapor and studied its absorption spectra. Finally, they studied the spectra of electric arcs generated between electrodes of different materials. Iron electrodes gave rise to a spectrum that coincided with dark lines in the sun's spectrum, whereas copper electrodes did not produce such a spectrum. They concluded that the solar atmosphere contains iron, but not much copper, which seemed quite plausible since significant amount of iron is present in the earth and also in meteorites.

The work of Kirchhoff and Bunsen was a major landmark, even by modern standards. They determined wavelengths of thousands of spectral lines to an accuracy of one part in ten thousand. They spectroscopically discovered two new elements, rubidium and cesium. Their method was used to find fifteen more new elements before the end of the

19th century. In 1869, Joseph Lockyer studied the spectra of solar prominences (in eclipses). He found the spectra to be slightly Doppler shifted, from which he was able to deduce the speeds of the gases whirling around the sunspots. He also found a spectrum never seen before, and conjectured that it was due to the presence of a new element, named by him as Helium.

In fact, helium was subsequently discovered on earth in 1895 by Sir William Ramsay. At that time, it had just become evident that there was an inert component, argon, in the earth's atmosphere. Earlier, an inert gas was observed to emanate from uranium salts when they were heated. Ramsay assumed this would be the same gas, but decided to verify it. On heating uranium salts and performing a spectral analysis of the emitted gas, much to his surprise he found it to be helium. This is yet another example of the scientific method at work, viz. almost all important discoveries were made accidentally while looking for something else.

The spectrum of a neutral atom, produced by vaporizing the substance is called arc spectrum of the atom. It is the spectrum produced by means of an electric spark. The high temperature thus reached generates the spectrum lines from multiple ionization of atoms as well as of uncharged and singly ionized ones as distinct from arc spectrum. Also evaporation of the metal from the electrodes leads to additional spectral lines not associated with the gas through which the discharge takes place.

In general, when elements are heated or exposed to high voltage they emit light. The emitted light can be split into its constituent wavelengths by passing it through a diffraction grating or prism. This is called the emission spectrum which is unique for a given element and represents the spectral signature of the element. Commonly available metals such as iron, copper, zinc as well as non-metals, such as carbon, produce light when a large current is passed through a pair of electrodes placed apart with a small gap between them. The tips of the electrodes get heated up to a temperature of 3000-4000°C which produces light of distinct colors (wavelengths) which is characteristic of the element of the electrode. These arc lights are used in various applications.

At this temperature the electrodes melt and atoms escape, hence in addition to light, there is usually generation of noxious smoke, carbon dioxide, and possibly some amount of carbon monoxide as well as oxides of nitrogen [1].

Till high intensity gas discharge lamps were invented, motion picture projectors in movie theaters used carbon arc lamps. Sometimes the rods would need to be changed in the middle of the projection and the screen would go blank for a minute or two. The carbon arc itself is fairly bright, but the tips of the carbon rods are usually much brighter. Carbon arc lamps were also used in many physics experiments dealing with separation of various wavelengths in a spectrum.

Light emited from arc lamps covers a broad spectrum including IR and UV wavelengths (often in hazardous quantities if not filtered out). The UV part of the radiation contains significant UV-B and some UV-C (shortwave UV) which is hazardous to skin as well as eyes. Ordinary glass stops these radiations, but considerable amount of UV-A (long wave UV) gets through it which may be hazardous to eyes at high intensities. While performing experiments with arc lamps, one should use protective glasses similar to those commonly used by welders.

Theory

When a large current is passed through two closely held metal electrodes, it produces arc light which can be analyzed using a spectrometer. However, it is somewhat cumbersome to analyze this spectrum by a student spectrometer. Hence we have used a constant deviation spectrometer for this purpose. At present digital constant deviation spectrometers that are easily available have made this study much easier. Hence one can analyze a number of such electrodes, determine their spectral signatures and compare them with the corresponding standard wavelengths.

In this experiment we have used five different pairs of electrodes and their spectral signatures are photographed from which the wavelengths of light emitted are determined using digital CDS and compared them with the corresponding standard wavelengths. However, the wavelengths determined from such measurements may differ from their corresponding standard values due to problems of CDS calibration, impurities present in the metal electrodes etc. To account for these discrepancies, a parameter, called spectral sensitivity, is defined as

$$\text{Spectral sensitivity, } S_s = \frac{\Delta\lambda}{\lambda} \times 100\% \qquad \ldots 1$$

where $\Delta\lambda$ is the change in the wavelength; and

λ is the corresponding standard wavelength which is known from literature.

Smaller the magnitudes of this parameter, more accurate are the measurements.

For example, in the spectrum of Zinc for the three blue wavelengths, given in Table-1, the spectral sensitivity is calculated with respect to the corresponding standard wavelength which is also given in the table. Smaller the value of this parameter better is the spectral sensitivity of the instrument.

Table-1: Standard wavelengths of zinc and their spectral sensitivities

Standard wavelength (nm)	Observed wavelength (nm)	Difference in wavelength (nm)	S_S %
468.0	468.5	0.5	0.10
472.2	472.7	0.5	0.10
481.0	481.5	0.5	0.10

Apparatus required for arc spectrum study

a) Arc power supply

Arc spectrum study of metals and non-metals is made faster and much easier now by using digital spectrometer, good DC power supply, and digital camera. The experimental set-up consists of 0-75V/0-5A DC power supply and digital constant deviation spectrometer, as shown in Figure-2. The DC power supply consists of a Variac to vary the input to the isolation transformer rectifier and filter sections that provide pure DC output. A digital DC ammeter measures and records the currents passing through the electrodes.

b) Digital constant deviation spectrometer

In this experiment the conventional drum based constant deviation spectrometer is replaced by digital constant deviation spectrometer. A microcontroller based system records the wavelength with 0.5nm resolution and calibration of the spectrometer is done with a standard mercury spectrum. A digital camera can be replaced by eye piece that records the spectrum. There is no need to compare the spectrum recorded with the standard spectrum because the spectrometer reads wavelengths directly. By coinciding the spectral lines with the cross wire, one can read the wavelengths directly on the digital display. It is, therefore, much simpler and faster for carrying out spectroscopic studies. Thus one can analyze several pairs of electrodes and find their spectral signatures.

c) Arc stand

An insulated stand is provided along with the Arc Spectrum Experimental set-up to hold the electrodes in position. The upper electrode holder is provided with a rack-and-pinion arrangement by which the gap between the two electrodes can be adjusted. The rack and pinion arrangement is isolated from the rest of the stand so that there is no possibility of getting electric shock to the experimenter.

d) Standard Load

An inductive load is provided in series with the arc electrodes. When the two electrodes come close to each other, in the event of contact there will be a large current flowing through the electrodes that may damage the arc lamp power supply. Hence an inductive load is put in series with the arc electrodes. In the event of an electrode short circuit there will be only a small current flowing through the electrodes as a result of the inductive load which will protect the power supply.

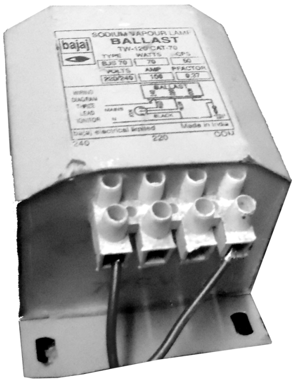

Figure-1: Choke, inductive load used in series with the electrodes

Apparatus used

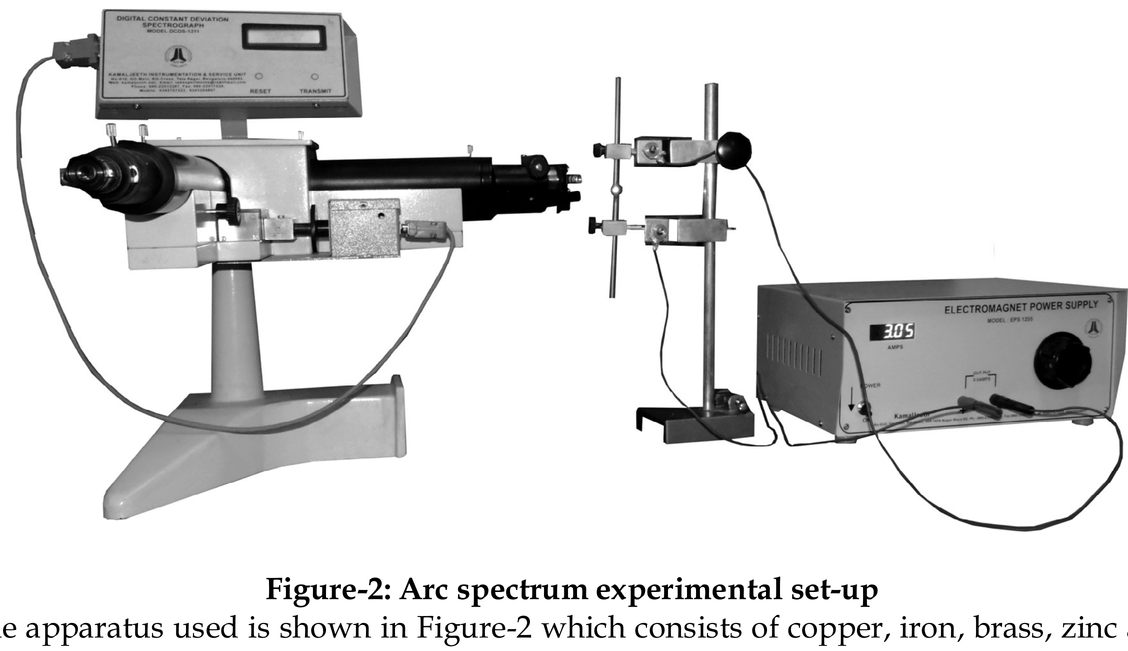

Figure-2: Arc spectrum experimental set-up

The apparatus used is shown in Figure-2 which consists of copper, iron, brass, zinc and carbon and aluminum electrodes, electrode stand, arc lamp power supply, standard load, and digital camera.

Experimental procedure

1. A pair of zinc electrodes is selected and one end of these is cleaned and made pointed by sharpening with the help of a grinder, as shown in Figure-3.

2. The electrodes are fixed on to the stand as shown in Figure-4 and electrical connections are made as shown in Figure-5.

3. The upper electrode is moved down so that it touches the lower electrode and current starts flowing by adjusting the height using the rack and pinion arrangement provided on the electrode stand.

4. The 'Set-voltage' knob of the power supply is adjusted such that continuous light is obtained which illuminates the slit of the DCDS, as shown in Figure-6.

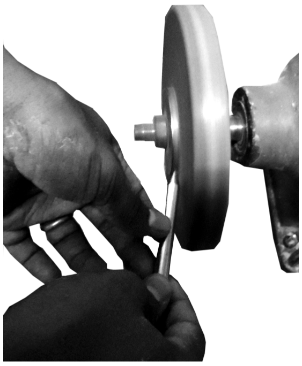

Figure-3: Sharpening the electrode tip with a grinding machine

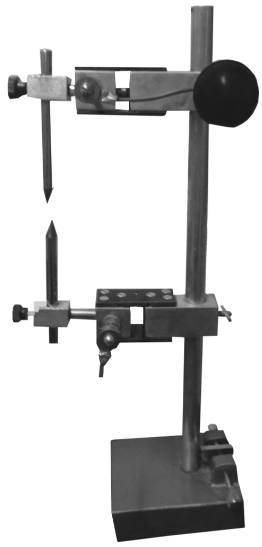

Figure-4: Two electrodes fitted on to the stand

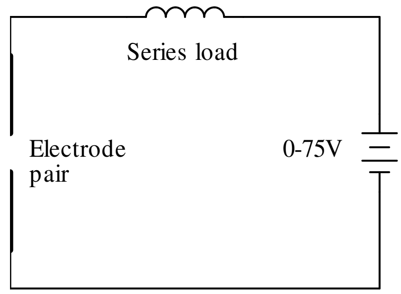

Figure-5: Electrical connections

1. The spectrum produced by the arc light is observed through the eye piece. Zinc produces a triplet in the blue region. The wavelength of each of the lines is recorded by coinciding with the respective spectral lines with the cross wire of the DCDS

2. The bright (triplet) lines observed for Zinc are shown in Figure-7 and their wavelengths are found as

   λ_{cyan1}= 479.6nm
   λ_{cyan2}= 471.6nm
   λ_{cyan3}= 468.1nm
   λ_{red} = 647.8nm

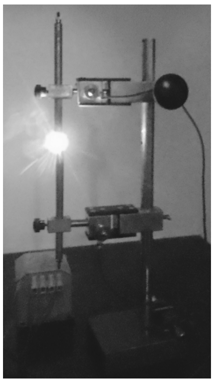

Figure-6: Zinc electrodes producing arc light, illuminating the DCDS slit

Figure-7: Zinc spectrum, the leftmost being red followed by green as well as the cyan triplets

3. The spectrum is photographed using the digital camera provided along with the set-up. The eye piece is removed and replaced by camera and the spectrum is observed. The color photograph is compared with the standard spectrum given in the web or with the standard wavelength of Zinc.

   The spectral sensitivity is calculated using the Equation-1. For cyan sensitivity of the DCSD

   Spectral sensitivity of DCDS $S_s = \frac{\Delta\lambda}{\lambda} x100\% = \frac{479.6-481}{481} x100\% = 0.29\%$

4. The experiment is repeated for copper, brass, iron, aluminium and carbon electrodes one by one. Figures-8 to 12 shows the arc spectrum of copper, brass, iron, aluminium and carbon. Spectral sensitivity of the DCDS is calculated as in the case of Zinc electrodes. Tables-2 to 6 show the observed emission lines of copper, brass, iron, aluminium and carbon vis a vis the corresponding standard wavelengths and their spectral sensitivitities.

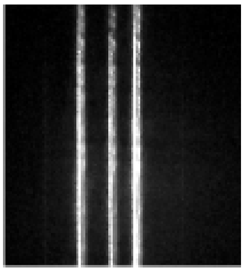

Figure- 8: Observed copper spectrum
(Colored picture shown on the cover page of this issue of LE)

Table-2: Copper Spectral lines

Material	Wavelength (nm)		Spectral sensitivity (%)
	Observed	Standard	
Violet-1	400.9	400.3	0.14
Violet-2	404.0	405.0	0.24
Blue-1	425.6	425.8	0.04
Blue-2	465.4	467.4	0.42
Green-1	511.0	511.1	0.02
Green-2	515.0	514.4	0.11
Green-3	524.5	520.0	0.86
Green-4	531.5	535.2	0.69
Yellow-1	574.6	573.2	0.24
Yellow-2	581.5	NA	-

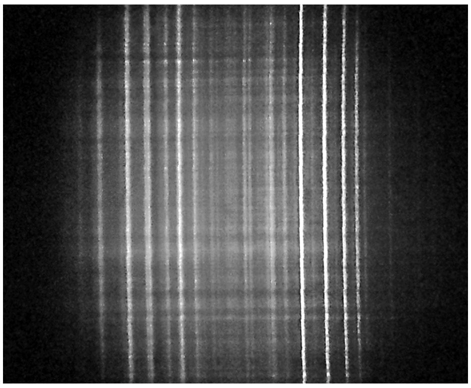

Figure-9: Brass spectrum showing prominent lines in cyan-green region
(Colored picture shown on the cover page of this issue of LE)
Table-3: Spectral lines of Brass

Material	Wavelength (nm)		Spectral sensitivity (%)
	Observed	Standard	
Violet-1	403.0	NA	-
Violet-2	426.8	NA	-
Green-1	471.0	465.0	1.29
Green-1	471.9	468.0	0.83
Green-1	480.6	472.0	1.82
Green-1	514.1	NA	-
Green-1	515.5	NA	-
Green-1	523.0	NA	-
Yellow-1	569.6	NA	-
Yellow-2	581.9	NA	-
Red	645.5	NA	-

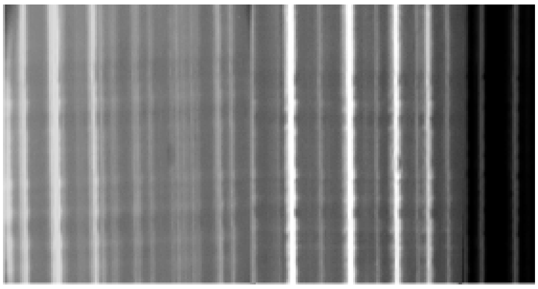

Figure-10: Observed iron spectrum with violet, cyan and green lines
(Colored picture shown on the cover page of this issue of LE)

Table-4: Spectral lines of Iron

Material	Wavelength (nm)		Spectral sensitivity (%)
	Observed	Standard	
Violet-1	415.7	415.6	0.02
Violet-2	417.1	417.5	0.09
Violet-3	422.8	422.7	0.02
Violet-4	425.2	425.3	0.02
Violet-5	428.0	428.3	0.07
Violet-6	429.9	430.0	0.02
Violet-7	434.9	435.0	0.05
Violet-8	437.5	437.0	0.11
Green-1	490.3	490.8	0.10
Green-2	492.8	495.7	0.58
Green-3	520.7	520.2	0.22
Green-4	522.1	522.6	0.09
Green-5	525.6	526.6	0.18
Green-6	531.0	532.4	0.26

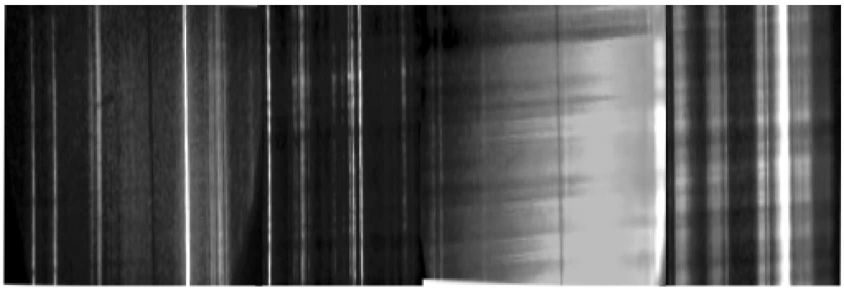

Figure-11: Observed carbon spectrum from violet to red region

Table-5: Spectral lines of Carbon

Material	Wavelength (nm)		Spectral sensitivity (%)
	Observed	Standard	
Blue-1	421.8	426.7	1.14
Blue-2	441.1	NA	-
Blue-3	442.6	NA	-
Green-1	531.8	538.0	1.15
Green-2	553.9	NA	-
Green-3	561.8	NA	-
Yellow	587.3	587.3	0
Orange	600.0	601.3	0.21
Red	628.0	NA	-

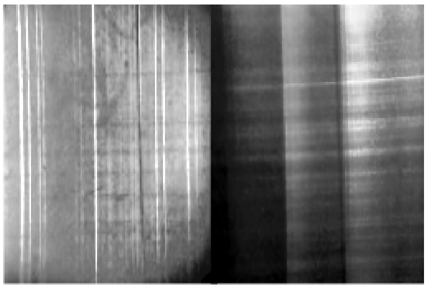

Figure-12: Observed aluminum spectrum from ultra violet to green region

Table-6: Spectral lines of Aluminum

Material	Wavelength (nm)		Spectral sensitivity (%)
	Observed	Standard	
Violet-1	399.0	396.1	0.73
Violet-2	400.2	NA	-
Violet-1	401.6	NA	-
Violet-1	402.8	NA	-
Violet-1	403.0	NA	-
Violet-1	404.5	NA	-
Blue	436.9	NA	-
Green	516.8	NA	-
Yellow	582.4	NA	-

Results and Conclusions

1. The prominent spectral lines observed for various metal electrodes are listed in various Tables (2-6) given in the paper. The apparent colour of the arc light and corresponding wavelengths is unique for a given pair of electrodes and gives the spectral signature of the elements(s) of the electrode. Following Table shows the colour of the arc light for various electrodes.

Experimental results

Electrodes	Arc light color	Prominent wavelengths
Zinc	Blue	Blue triplet
Copper	Green	Green triplet
Brass	Cyan	Cyan
Iron	White	Vibgyor colors
Carbon	Super white	Vibgyor Colors
Aluminum	Dull White	Vibgyor colors

2. The wavelengths recorded by the DCDS are listed in Tables- 2 to 6 along with their sensitivities of the DCDS calculated from the knowledge of their standard wavelengths. It is observed that the wavelength recorded by the DCDS is quite accurate because sensitivity <3% maximum and almost all the known emission lines are present in the observed spectrum.

3. Zinc exhibits three distinct blue emission lines which can be considered as its spectral signature.

4. Carbon gives very bright light, distinct lines in the entire wavelength region

5. Copper gives spectral lines in the blue-green region of the spectrum

6. Iron gives bright lines in green yellow and red regions.

7. Further some IR lines (in the case of Brass) and UV lines (Aluminium) were also seen in the spectrum

8. Photographing is little tedious compared to other electrodes; in the case of aluminium (disrupted light of aluminium) and carbon (extra bright light of carbon). Hence extra care is required in photographing this spectrum.

References

[1] http://galileo.phys.virginia.edu/classes/252/spectra.html

[2] http://link.springer.com/article/10.1007%2FBF00815874#page-1

[3] http://thesciencedictionary.org/spark-spectrum/