SPECTRAL CHARACTERISTICS OF FLASH DISCHARGES

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A "flash" discharge may be defined as an electrical breakdown produced by the discharge of a condenser through a gas at pressures of the order of 100 mm of mercury. It is characterized by a high current pulse of short duration accompanied by a brilliant white flash of light. The duration of the current pulse is of the order of 10 microseconds while the period of the light flash may be considerably longer, persisting for 100 microseconds or more in heavy discharges.

Many practical uses have been found for such lamps. Originally developed for high-speed photography and stroboscopic uses, they have more recently been employed in aerial photography, as a source of artificial sunlight in making moving pictures, and for emergency lighting of landing fields. Figure 1 shows several types of flash lamps. A, B, C, and G are forms of commercial photo-flash lamps; D, E, and F are examples of experimental models of flash tubes.

The maximum brightness of these lamps when used to produce single heavy discharges may exceed the brightness of the sun by a factor of ten with a peak flux output of a hundred million lumens. Currents of several thousand amperes are produced with instantaneous rates of energy input of several megawatts.

The physical characteristics of the emitted radiation are of considerable scientific interest. In the first place, the main component of the radiation is an intense continuum in the case of discharges where the current density is 20,000 amp/cm^2 or higher. This in itself is unusual, since normally a gas is expected to radiate chiefly bright lines characteristic of the excited atoms and molecules present in the discharge.

In the second place, the line spectra which appear superimposed on the continuous background exhibit many anomalies when compared to the lines emitted by low intensity arc discharges in the same gas. A study has been made of these anomalies, both with reference to the energy input per flash, and also as a function of time during the various phases of the flash. This paper attempts only a very brief summary of the results of this study.

The Continuum

When measurements are made of the energy distribution of the continuum in the "integrated" flash, a broad distribution is found as a function of wave length. In the case of intense discharge a maximum occurs at about 4500 AU, corresponding to a black body temperature of roughly 10,000°K. The radiation density values, however, indicate much higher temperatures.

Most theories agree in ascribing the origin of these continuous wave lengths to "free-free" electron transitions with ions in the high density plasma existing in these discharges, and also to electron-ion recombination, or "free-bound" tran-

COMPARISON OF XENON ARC AND FLASH SPECTRA
(3,500 to 6,200 A.U.)

λ(A.U.)	Spectrum I	Spectrum II	Transition	D.C. Arc	45 Watt Flash	720 Watt Flash	Xe^+	Xe
6098		x	$(^3P)\ 5d\ ^4D_{5/2} - (^3P)\ 6p\ ^4P^o_{3/2}$			x	II	
6036		x	$(^3P)\ 5d\ ^4D_{5/2} - (^3P)\ 6p\ ^4P^o_{5/2}$			x	II	
5976		x	$(^3P)\ 6s\ ^4P_{3/2} - (^3P)\ 6p\ ^4P^o_{5/2}$			x	II	
5824	x		$1s_3 - 5X$	x				
5668		x	$(^3P)\ 5d\ ^4D_{3/2} - (^3P)\ 6p\ ^4P^o_{1/2}$			x	II	
5473		x	$(^3P)\ 5d\ ^4D_{7/2} - (^3P)\ 6p\ ^4D_{7/2}$			x	II	
5419		x	$(^3P)\ 6s\ ^4P_{3/2} - (^3P)\ 6p\ ^4D^o_{5/2}$		x	x	II	
5372		x	$(^3P)\ 6s\ ^4P_{3/2} - (^3P)\ 6p\ P^o_{1/2}$			x	II	
5339		x	$(^3P)\ 6p\ ^4D^o_{3/2} - (^3P)\ 6d\ ^4D_{7/2}$		x	x	II	
5292		x	$(^3P)\ 6s\ ^4P_{5/2} - (^3P)\ 6p\ ^4P^o_{5/2}$		x	x	II	
5191		x	$(^3P)\ 6s\ ^4P_{1/2} - (^3P)\ 6p\ ^4D^o_{1/2}$			x	II	
5122		x	$(^3P)\ 6p\ ^4P^o_{1/2} - (^3P)\ 7s\ ^4P_{3/2}$			x	II	
5081		x	$(^3P)\ 6p\ ^4D^o_{5/2} - (^3P)\ 7s\ ^4P_{3/2}$			x	II	
5028	x		$1s_4 - 3p_{10}$	x				
4923	x		$1s_4 - 3p_9$	x	x	x		I
4917	x		$1s_4 - 2p_4$	x	x			
4884		x	$(^3P)\ 6s\ ^4P_{1/2} - (^3P)\ 6p\ ^4S^o_{3/2}$			x	II	
4844		x	$(^3P)\ 6s\ ^4P_{5/2} - (^3P)\ 6p\ ^4D^o_{7/2}$		x	x	II	
4843	x		$1s_4 - 3p_6$	x	x			
4830	x		$1s_4 - 3p_7$	x	x			
4807	x		$1s_4 - 3p_5$	x	x			
4734	x		$1s_4 - 2p_3$	x	x	x		I
4671	x		$1s_5 - 3p_8$	x	x	x		I
4624	x		$1s_5 - 3p_6$	x	x			
4603		x	$(^3P)\ 6s\ ^4P_{3/2} - (^3P)\ 6p\ ^4D^o_{3/2}$			x	II	
4545		x	$(^3P)\ 6p\ ^4D^o_{5/2} - (^3P)\ 6d\ ^4D_{7/2}$			x	II	
4525	x		$1s_5 - 2p_3$	x				
4501			$1s_5 - 2p_2$	x				
4481		x	$(^3P)\ 6p\ ^4D^o_{3/2} - (^3P)\ 6d\ ^4F_{5/2}$			x	II	
4415		x	$(^1D)\ 6s\ ^2D_{5/2} - (^1D)\ 6p\ ^2D^o_{5/2}$			x	II	
4393			$(^3P)\ 6p\ ^4S^o_{3/2} - (^3P)\ 6d\ ^2D_{5/2}$			x	II	
4386	x		$1s_4 - 4X$	x				
or 4384	x		or $1s_4 - 4Y$					
4331		x	$(^3P)\ 6p\ ^4D^o_{5/2} - (^3P)\ 6d\ ^4F_{7/2}$			x	II	
4194	x		$1s_5 - 4U$	x				
3968	x		$1s_5 - 4p_8$	x				

TABLE 1.

sitions. The latter mechanism would be expected to be the predominant cause of continuous radiation in the "afterglow," or decaying portion of the light flash which persists after current ceases to flow in the arc.

To obtain a complete analysis of the electrical and radiation properties of these discharges it is necessary to make measurements as a function of time during the very short period of the flash. This is difficult in the case of the ordinary spark discharge across a gap at atmospheric pressure because of the extremely erratic behavior of the spark. However, by employing rare gases to avoid chemical reactions, and pressures of from 25 mm to 100 mm Hg, it is possible to obtain highly reproducible flash discharges in repetitive operation. The flash can be initiated with great precision, and accurate reproduction of current, potential, and photo-current showing the change of radiation intensity with time can be obtained on the oscilloscope screen.

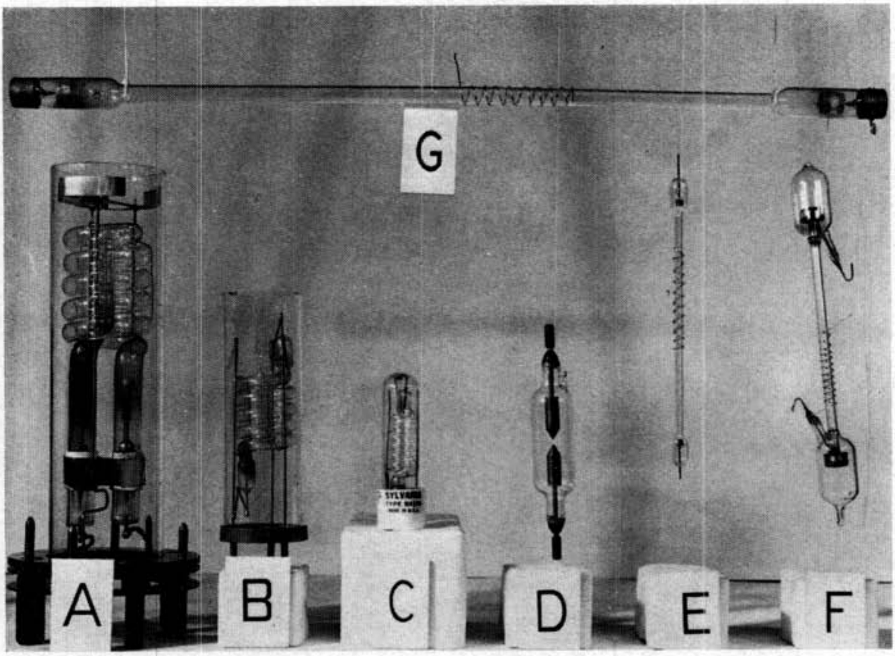

FIG. 1.—Types of commercial and experimental flash tubes.

Figure 2 illustrates how the current and the continuous radiation change with time for flash discharges in argon and neon tubes. These discharges are "triggered" by means of a sharp voltage pulse applied to an auxiliary electrode which causes enough ionization for a heavy arc current to form and discharge a condenser attached to the electrodes. These traces are taken from the oscilloscope screen.

Three types of phototube multipliers were used to register the intensity of radiation in three spectral regions: the ultraviolet (2400 to 4200 AU), visible (4600 to 7000 AU) and the near infrared (7000 to 12,000 AU). In obtaining these results the amplitude of each photocurrent plot was arbitrarily adjusted, so they cannot be intercompared. The total radiation in the visible and ultraviolet regions is much greater than in the infrared. It is noted that in all cases the peak light occurs much later than peak input current (or power), this lag being greatest for the longer wave lengths.

VARIATION OF CHARACTERISTIC LINE SPECTRA

A study of the line spectra is of particular interest to the physicist who desires information concerning fundamental processes occurring in this type of discharge. He wishes to determine the processes leading to breakdown of the gas, the current conduction mechanism, temperatures and ion densities in the column, the cause of the lag of radiation behind current, and the nature of the processes occurring in the gas plasma during the afterglow period. In general, our knowledge of the detailed processes occurring in the flash and spark discharges is quite incomplete compared to our

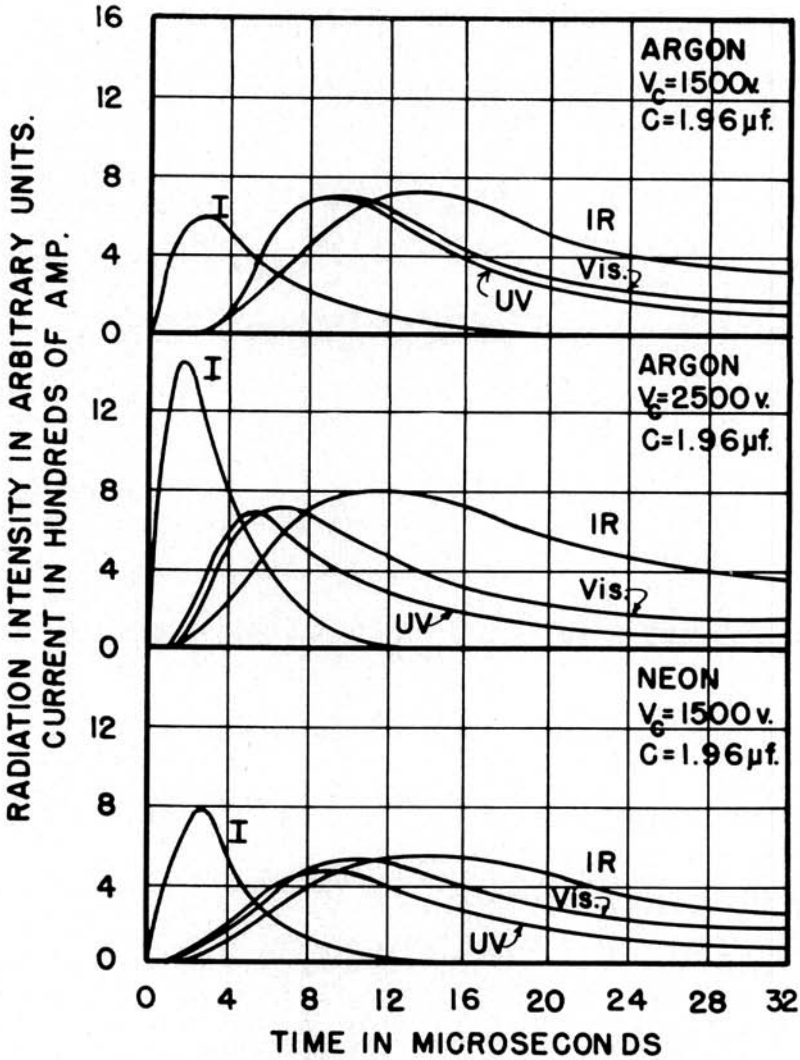

FIG. 2.—Oscillographic traces of current and radiation in argon and neon quartz flash lamps.

understanding of other types of steady discharges.

Spectrograms were made of discharges in xenon for the total flash period, and compared with the lines appearing in a low current steady arc discharge in the same gas. Table 1 gives a summary of results for the strong lines observed in the visible region. In the d-c low current arc only arc lines (Xe I) are observed. For low energy flashes a number of these same arc lines are observed, and in addition several spark lines (Xe II) appear, lines which are due to excitation of xenon ions. Lines appearing superimposed on the strong continuum in the high energy flash discharge are shown in the column on the right. Here only

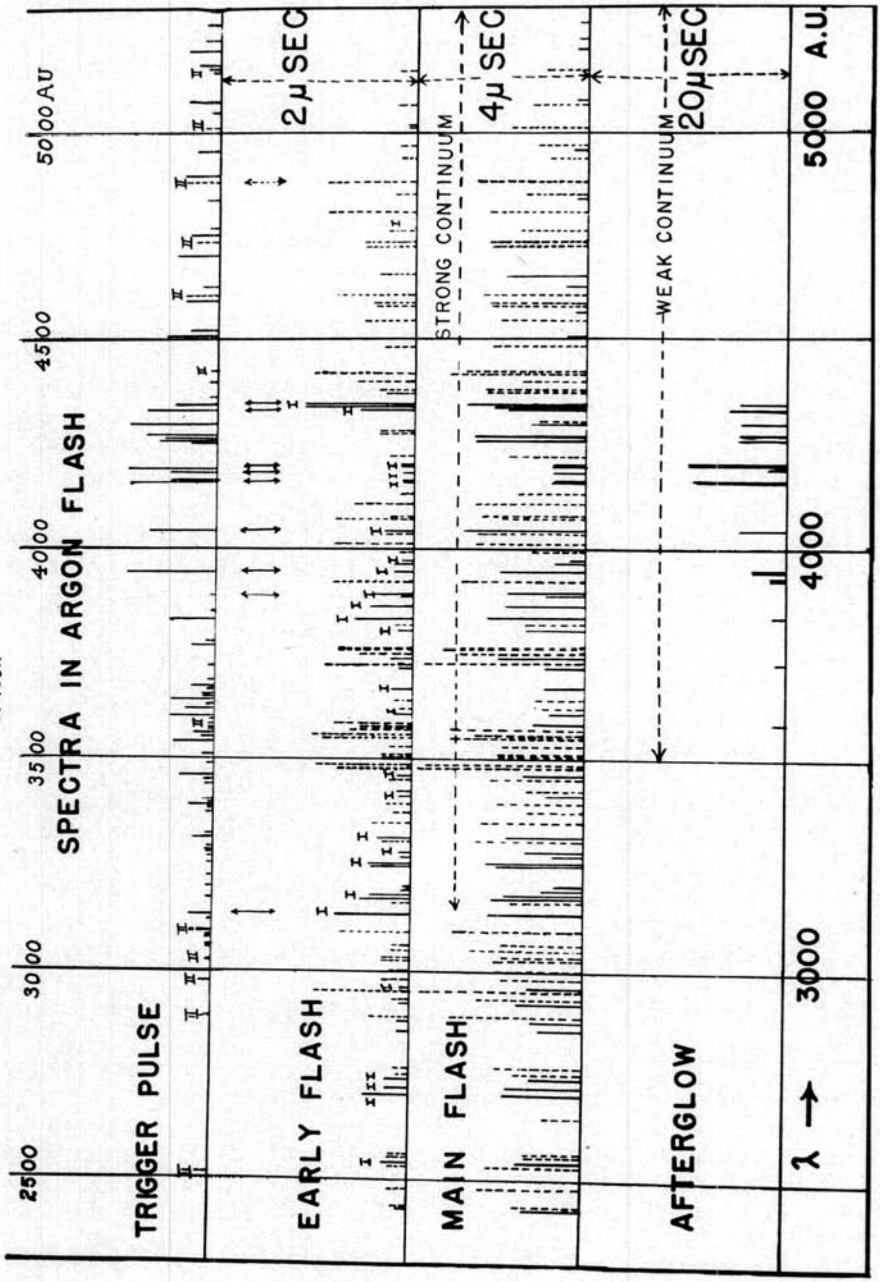

FIG. 3.—Variation in line spectra at various phases of a flash discharge in argon.

three arc lines show strongly, while twenty intense lines of the xenon ionic spectrum are identified. Similar results were obtained using other gases.

The question now arises as to how the spectrum varies with time over the entire flash period. A large number of observations were carried out using flash tubes filled with neon, argon, krypton and xenon. An example of such an analysis will be shown only for an argon-filled tube.

A method was developed for observing through a fine slit in a ten-inch disc driven by a synchronous motor, the light from the discharge at a given phase of the flash period. The particular instant in the flash when a spectrogram was taken could be varied by means of a phase changer which varied the time when the discharge was triggered with reference to the time of observation. The slit was of such a width that the observation interval was about three microseconds. Thus the emitted radiation could be photographed at any phase of the flash period in steps each three microseconds long.

Figure 3 is a chart of the results obtained using a quartz prism spectrograph. Relative photographic intensities for a given exposure are indicated by the height of the plotted lines. Solid lines are for atomic spectra (A I); dotted lines represent spark spectra (A II). The rate of synchronous flashing was one per second. However, for the weak light emitted by the trigger pulse, which occurs about 2 microseconds before the main current of the discharge begins, a higher rate was used with the discharge condensers disconnected. Thus, the exposure time for the upper section of the chart was about 300 times longer than for the other pictures. For the afterglow the exposure time was about 10 times longer than for the main flash.

The changes in relative intensities of the lines is very striking. Very few strong spark lines occur in the trigger pulse at high potential. At current peak (early flash) and at peak radiation intensity the line spectrum is predominately that of the spark, or second spectrum (II), of argon ions: some 44 relatively weak arc lines, compared to 71 spark lines of high average intensity. Late in the discharge only a few weak arc lines appear, the relative intensities of which are quite different from those appearing in the trigger pulse spectrum, or in the main discharge. The strongest set of four arc lines in the afterglow have very low intensities in the main flash relative to other lines appearing at the same time.

Conclusions

From this study of the spectral characteristics of synchronized flash discharges in rare gases the following conclusions may be drawn:

(1) The overall integrated line spectrum constitutes a small fraction ($<10\%$) of the useful light emitted by the discharge, the main radiation flux in the visible and ultraviolet regions being an intense continuum.

(2) In the short wave infrared region, measurements show that for heavy rare gases (argon, krypton, and xenon) the line spectra, consisting largely of arc lines, contributes about half the total light flux.

(3) The characteristic lines observed at the instant of peak radiation intensity are predominately those of excited ions, indicating the existence of a plasma having a high degree of ionization. Calculations

show that in the discharge column from 80 to 90% of the atoms may be ionized.

(4) The spectrum of the trigger pulse, excited when a 10,000 volt potential is suddenly applied to an external electrode, shows that high fields do not necessarily excite a strong spark spectrum. *Rather, a strong spark spectrum is characteristic of the high current, low voltage arc phase of the spark discharge.* Recent observations in high current steady arcs verify this conclusion.

(5) The presence of only atomic spectral lines in the afterglow indicates the absence of impact excitation at low electron temperatures. Here the lines arise from electron-ion recombination only, the relative intensities being characteristic of this process and quite different from those shown during the high-temperature phase of the discharge.