Technical Report
June 1, 1964

Contract NsG-178-61 on

Vacuum Ultraviolet and Solid State Physics

INSTRUMENTATION PROBLEMS
IN THE VACUUM ULTRAVIOLET BELOW 1000 Å

by

G. L. Weissler
Chief Investigator
Contract No. NsG-178-61

Preprint of an invited paper to be presented at the
"International Conference on Photographic and Spectroscopic Optics,"
Tokyo and Kyoto, Japan, Sept. 1-8, 1964

Prepared for

Office of Grants and Research Contracts
National Aeronautics and Space Administration
Washington, D. C. 20402

INSTRUMENTATION PROBLEMS IN THE VACUUM ULTRAVIOLET BELOW 1000 Å

G. L. Weissler
University of Southern California, Los Angeles, U. S. A.

Considerable progress has been made during the last ten to fifteen years in the field of Vacuum Ultraviolet Radiation Physics, primarily because of the development of new spectrographs and monochromators, new light sources, and new and more sensitive detectors. Much of this growth in instrumentation knowledge has come from well known research groups[1] in a variety of countries, and it is not intended here to summarize their work. Instead, a limited number of recent developments in the vacuum u.v. laboratories at U.S.C. will be presented.

One of the most useful light sources to be developed grew out of a configuration which was originally operated by Lyman.[2] In essence, a line spectrum originating from highly excited atomic levels is produced by discharging a condenser at high voltage through a capillary 2 to 3 mm in diameter and about 50 mm long. The pressure of the carrier gas, argon, air, or others, which fills this capillary, is in the range from 0.1 to 10 mm Hg. If a condenser of more than 1 μF is charged to more than 20 KV, then considerations of power dissipation limit the operation to about one discharge per second or less. On the other hand, if this condenser is less than 0.1 μF and is charged to less than 20 KV (but more than 10 KV), then the capillary spark source may be operated at a rate of between 10 and 100 discharges per second.

While the slower mode of operation[2,3,4] has many applications, particularly when used with photographic detection, the following treatment will apply specifically to the faster mode of 10 sparks per second or more.[5] Operational details of such a source are omitted here, since no exhaustive parametric studies have been made as yet. Suffice it to say, that the emission of high-intensity lines, a requirement for many research problems, seems to depend in some functional form firstly on the absolute magnitude of the spark current pulse and secondly on the rate-of-rise of this current with time. These required large current surges may well interfere with the circuitry of a detector system behind the exit slit of a monochromator, such as a photomultiplier, an ion chamber, or a thermocouple radiation detector.

At the risk of repeating the obvious, it is essential to integrate the transmission lines (from the discharge condenser to the light source electrode) with the vacuum housing of the source in such a fashion that these conductors are not free to radiate rf energy into space. To accomplish this, a cylindrical, co-axial system has been constructed such as to make the outer cylinder the ground return, which shielded nearly completely the inner co-axial high-voltage line and spark gap. For the sake of power dissipation it was found necessary to water-cool both the high-voltage and the ground electrode of the spark gap. Boron nitride, BN, is a new ceramic which can be machined to the desired dimension and which seems to work best as a capillary material, allowing for nearly continuous operation for a period of months.

With the exception of a few designs,[6,7] the capillary spark sources are usually viewed end-on, with the capillary axis coincident with the optic axis. Since each discharge generates its own shock front travelling a few cm/μsec, the spark plasma after leaving the open end of the ceramic capillary will propagate in the direction of the primary slit and may find its ground return not only through the outer cylinder of the co-axial system but also through a secondary grounding loop involving the metal walls of the spectrograph or monochromator. This may result in the undesirable transmittal of rf noise to the detector system. For this reason, it has been found useful to do two things: 1. to provide an expansion chamber for the grounded electrode of the spark gap, which is made part of the co-axial system and allows for lateral dissipation of the shock plasma of each spark, and 2. to insulate the light source chamber electrically from the metal housing of the monochromator and associated vacuum systems. Such separation and shielding of pulsed sources may well increase detector sensitivity by an order of magnitude.

An additional increase in sensitivity may be accomplished by using synchronous signal handling techniques, in which one electronically multiplies the actual noisy signal from some detector system with the known waveform of the noise-free signal. As an approximation to this technique for the case of light pulses from sparks, one may simply gate the detector "on", allowing it to pass to a recording device only during such times when a signal might be present, and conversely rejecting the detector output during the interval when the source is known to be "off". Such synchronous detection has reduced the recorded spurious photon flux by about the duty cycle factor, namely, in this case 10 000, when the source was operated at about 30 sparks/sec and each spark resulted in a light pulse of about 3 μsec duration. This procedure has proven its effectiveness in measurements on low-intensity fluorescence in gases excited by vacuum u.v. radiation.[8]

The above outlined method on synchronous detection has been modified in conjunction with the use of thermocouple (or thermistor) radiation detectors behind the exit slit of a monochromator, yielding absolute rather than relative intensities in terms of photons/sec. Such instruments are black, that is wavelength independent, with respect to the incident radiation, and an electrical potential is generated across the junction when heated by this radiation. The time required to come to thermal equilibrium is of the order of 1/100 to 1 second, depending on construction. It is customary to amplify the dc output voltage of the thermocouple by converting it into an ac signal. As in a Liston-Becker breaker amplifier, this may be done by reversing the dc input signal polarity 16 times/sec (8 cps) with a motor-driven reversing switch. This signal is then amplified by a low-noise step-up transformer, followed by a conventional band pass amplifier, yielding an ac signal whose amplitude is proportional to the dc input, except for the noise added by the amplifier system. However, the broad-band noise can be almost entirely rejected by selecting from the amplifier output only the 8 cps signal. This is accomplished by the band pass amplifier (mentioned above) which is tuned to 8 cps.

Restoration to a final dc output signal is achieved by using another reversing switch behind the amplifier. The band width of such a system is thus determined by both the sharply tuned band pass amplifier and by any subsequent low-pass filter. When used in this fashion, source emission lines between 500 Å and 1000 Å have been detected behind the exit slit, yielding photon fluxes averaging 10^9 photons/sec or 10^8 photons per pulse, as shown in Table I.

In order to increase the sensitivity of this detection system further by eliminating drifts and small ambient temperature changes, a mechanical chopper has been employed to modulate the incident source radiation at 8 cps. This in turn provides now the required ac signal input to the above amplifier, and its input reversing switch is therefore by-passed. The amplified ac output signal is converted as before to dc with a reversing switch, which is synchronously phased with the mechanical chopper. This removes from the amplifier output nearly all temperature changes of the thermocouple which are not caused by radiation from the light source.

An alternate method to the mechanical beam chopper is now being tested. This consists of modulating the light source itself in such a fashion, that a group of sparks will be fired during an interval of 1/16 sec followed by a cooling period of 1/16 sec. It is hoped that this will allow for a doubling of the useful electrical power dissipated in the source without sacrificing any of the above mentioned advantages in detection.

With such a combination of properly shielded and modulated spark sources together with detection systems as outlined above,

Table I.

Photon Flux Measurements of some Emission Lines

Wavelength, Å	Element	Photons/sec	Microwatts
1084	N II	1.92 x 10^{10}	0.035
991	N III	2.70	0.055
980	N III	1.41	0.029
923	N IV	2.94	0.063
916	N II	1.35	0.029
835	O III	3.86	0.093
796	O II	0.43	0.011
775	N II	2.32	0.060
765	N III	2.6	0.068
718	O II	0.65	0.018
702	O III	1.39	0.039
685	N III	3.17	0.092
672	O II	0.50	0.015
644	N II	0.35	0.011
610	O III	0.26	0.008
599	O III	0.29	0.009
554	O IV	0.196	0.007
507	O III	0.197	0.008

it is estimated that many more source emission lines beyond the 50 odd at present will be amenable to photon flux measurements. In particular, it is planned to extend these techniques into the short wavelength region, perhaps down to less than 100 Å, available only in grazing incidence instruments. Efforts in this direction are now under way.

Another aspect of the emission spectrum of impulse-operated light sources is the continuous background. Often, electrical parameters and carrier gases can be chosen such as to minimize emission lines in order to facilitate the observation of molecular absorption bands as obtained by Tanaka[9] and others.[2] However, at short wavelengths, between 50 Å and 500 Å, the quality of this continuum is ambiguous not only because of overlapping orders but also because of the presence of scattered radiation near the zero order or central image.

While a separation of orders in the visible and near ultraviolet regions of the spectrum can be accomplished easily by a pre-disperser prism or by filters, at wavelengths shorter than 1000 Å a pre-disperser foregrating mounted at grazing incidence has been used by Douglas and Herzberg[10] in conjunction with a 3-m radius of curvature normal incidence spectrograph. Tousey's group[11] also used a pre-disperser curved grating with a normal incidence spectrograph down to 499 Å. However, their foregrating produced a dispersed spectrum along the line of the primary slit, i.e. perpendicular to the plane of the Rowland circle of the normal incidence spectrograph. Due to this crossed dispersion, the visible and near ultraviolet are dispersed beyond the end of the primary slit and stray light is reduced by several orders of magnitude. They also used this method in a modified form[12] to analyse the profile of the solar emission of Lyman-α.

With the aim of isolating various wavelength regions below 500 Å, a pre-disperser plane grating of 600 grooves/mm ruled lightly on glass was placed between the capillary spark source and the primary slit of a grazing incidence spectrograph, as indicated schematically in Fig. 1. The pre-disperser grating could be translated along a line perpendicular to the optic axis and independently rotated about an axis coincident with its center groove. When the foregrating had been translated to a position off the optic axis, light from one ceramic spark source would fall directly onto the primary slit, and a photographic spectrum could be obtained with a few seconds exposure time. Then this auxiliary grating could be moved so as to intersect the optic axis. When in this new position, its plane would be rotated to a pre-determined angle, for instance such that only dispersed light between 100 Å and 200 Å emitted from a second ceramic spark source would be allowed to reach the primary slit of the grazing incidence spectrograph. The following Fig. 2 shows the microdensitometer traces of exposures with and without the use of a pre-disperser grating.

It is to be noted that in the uppermost exposure of Fig. 2 (no pre-disperser), the continuous background amounts to about 40% of maximum deflection, while in contrast in the lower exposures (with pre-disperser) this background was reduced to such an extent that it could not be distinguished from the density of a clear portion of the photographic plate.

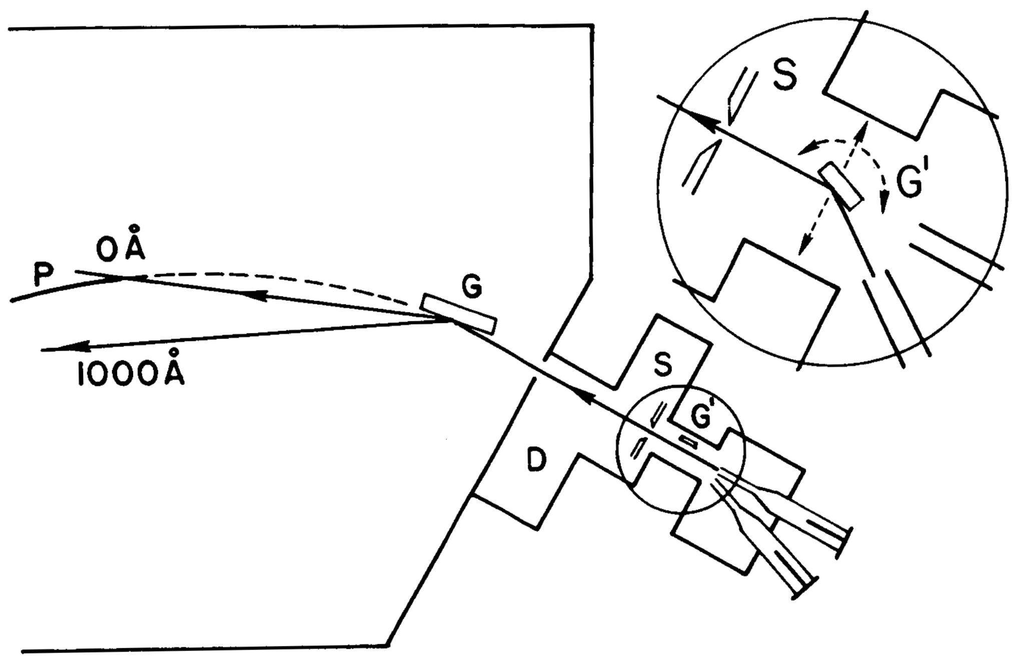

Fig. 1

Optical arrangement of 2 meter vacuum spectrograph with pre-disperser grating. Radiation from one source passes directly through the primary slit (S), and from the other is dispersed by foregrating (G'). (G) denotes the position of the main grating and (P) the photographic plate. The inset shows the rotation of the pre-disperser grating, for selecting the passband $\Delta\lambda$, and the lateral motion, which removes it from the direct beam.

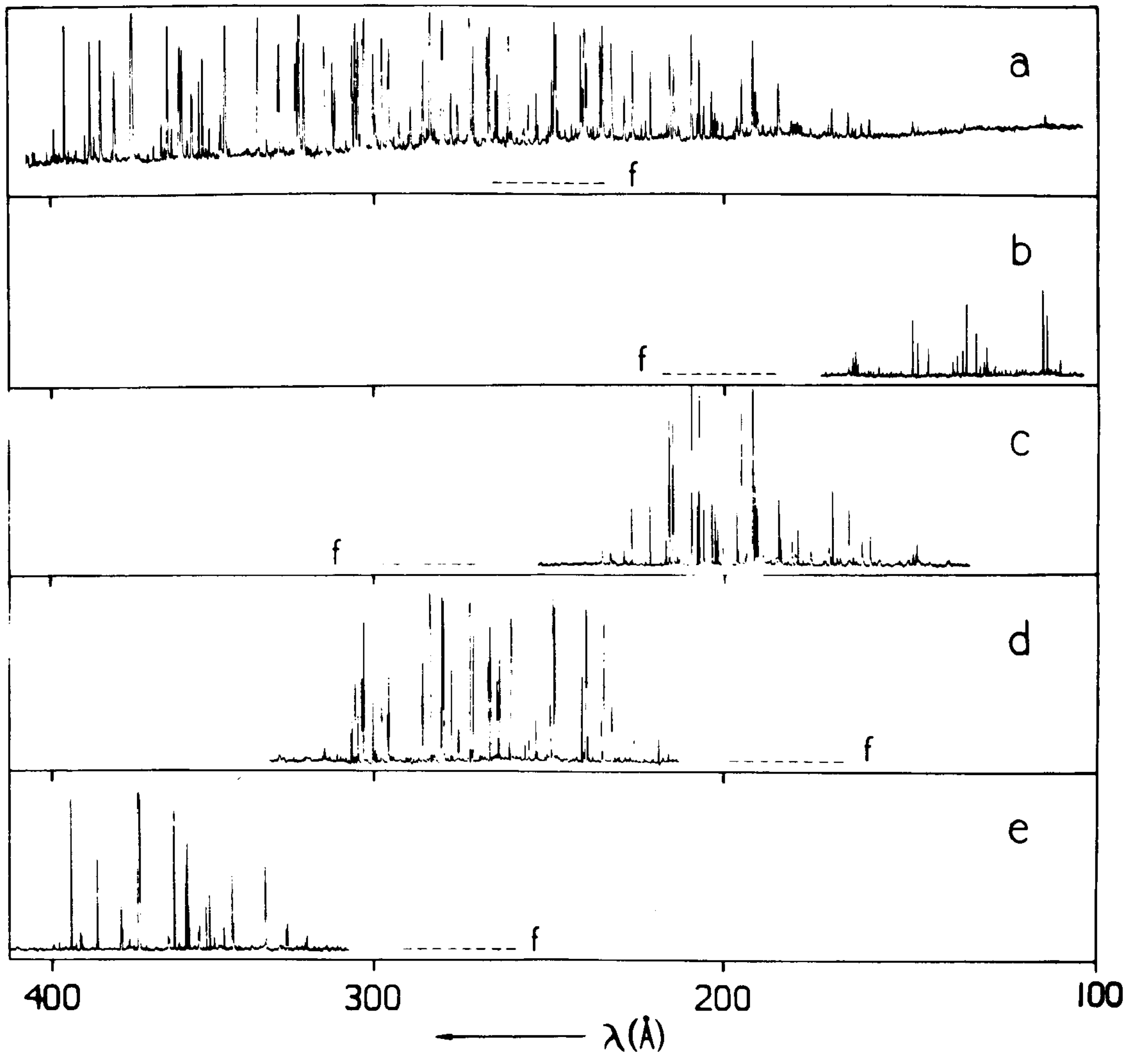

Fig. 2

Microphotometer recording showing the spectrum of both direct and pre-dispersed radiation. (a) shows the direct spectrum with a strong background and superimposed lines, 10 sec; (b) the pre-dispersed radiation with G' at an angle of 8 3/4°, 6 min; (c) 8°, 1 min; (d) 7 1/4°, 1 min; (e) 6 1/2°, 1 min. The plate fog level is indicated in each case by a dashed line.

This result assumes increased significance when it is realized that for a straight through exposure (without pre-disperser) an increase in exposure time does not provide a better developed image: the Si V 117.86 Å line was indistinguishable from the local plate fog, which was measured with a densitometer to be about 10% of full deflection (black) for a 5 sec exposure; for a 10 sec exposure, the local density corresponded to 40% deflection and the Si V-line appeared as a 3% deflection (barely visible); for a 15 sec exposure, the local density increased to 70% of full deflection with the Si V-line adding only 5% to this background.

It is believed that the line intensities obtained with the present foregrating are sufficiently high to be observable with a scanning exit slit and photomultiplier. Clearly, a further increase in intensity may be achieved, at least in a fixed wavelength region, if a curved and blazed foregrating were to be used as in the arrangements of Herzberg[10] and Tousey.[12] The arrangement presented here, using a plane, lightly ruled, glass grating, has the advantage of reasonable exposure times (1-6 min) combined with an easy selection of different wavelength intervals.

Acknowledgements

The help of Dr. M. Ogawa, D. L. Judge, A. L. Morse, and G. S. Shipp is hereby gratefully acknowledged, together with the support of the U. S. Office of Naval Research, the U. S. Army Research Office, Durham, and the National Aeronautics and Space Administration.

References

1. "First International Conference on Vacuum Ultraviolet Radiation Physics," Conference Proceedings: J. Quant. Spectrosc. Radiat. Transfer Vol. 2, pp. 315-728. Pergamon Press Ltd., 1962.

2. T. Lyman, Science 64, 89 (1926); R. E. Worley, Rev. Sci. Instrum. 13, 67 (1942).

3. J. C. Boyce, Revs. Modern Phys. 13, 1 (1941).

4. W. R. S. Garton, Rev. Sci. Instrum. 36, 11 (1959).

5. N. Wainfan, W. C. Walker, and G. L. Weissler, J. Appl. Phys. 24, 1318 (1953); Phys. Rev. 99, 542 (1955).

6. R. Ermisch, I. Physics Institute of the Free University of Berlin; reported at the April 19 to 20, 1963, meeting of the German Physical Society at Berlin.

7. G. Balloffet, J. Romand, and B. Vodar, Compt. rend. 252, 4139 (1961); also Spectrochimica Acta 18, 791 (1962).

8. D. L. Judge, A. L. Morse, and G. L. Weissler, Proc. of the VI International Conf. on "Ionization Phenomena in Gases," Paris, July 8-13, 1963, Vol. III, p. 373.

9. Y. Tanaka and T. Takamine, Sci. Pap. Inst. Phys. Chem. Res., Tokyo 39, 427 (1942).

10. A. E. Douglas and G. Herzberg, J. Opt. Soc. Am. 47, 625 (1957).

11. C. R. Detwiler, J. D. Purcell, and R. Tousey, Mem. Soc. Roy. Sci. Liège 4, 253 (1961).

12. J. D. Purcell and R. Tousey, Mem. Soc. Roy. Sci. Liège 4, 283 (1961).