4.1- and 5.1-Mev gamma-ray lines can probably be identified with the above 4.35- and 5.31-Mev nuclear levels. We cannot attempt to correlate the intensities of the gamma-ray lines with the intensities of the particle groups until the complete energy level scheme is known, because there may be alternative or competing ways in which an excited nucleus may make the transition to the ground state. As to our 6.6-Mev gamma-ray line, the particle ranges show that neither C^{12} nor N^{15} is formed on a level of that energy; therefore the line must arise as part of a complex transition from a higher level. The particle ranges also show that C^{12} is not formed on a level of 8 Mev, corresponding to our 8-Mev gamma-ray line, but do not preclude the possibility that the N^{15} is formed on that level. The protons in the latter case would have only 0.5 Mev, and would escape detection. One prediction can be made on the basis of the above argument: If the 8-Mev gamma-ray (and possibly others also) arises from an 8-Mev level in N^{15}, the intensities of these lines should be sensitive to the energy of the deuteron beam. This is because of the low energy of the ejected proton.

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Zeeman Effects in Complex Spectra at Fields up to 100,000 Gauss

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A newly constructed electromagnet of the Bitter type has been arranged to give fields up to 100,000 gauss, uniform to 1 percent over a volume of 25 cc. A special type of horizontal arc, with electrodes of salts compressed in silver powder, is operated at 4 amp. and furnishes light transversely to the field to three grating spectrographs, which can be used to cover the range 2000 to 8000A in a single exposure. Plane-polarized components of the light are separated with a 2-inch quartz Rochon prism, and exposures of 5 to 30 minutes give dense spectrograms at resolutions of 100,000 and greater. Plates in the ultraviolet region have been obtained for cerium, columbium, erbium, europium, gadolinium, iron, neodymium, praseodymium, rhodium, ruthenium, thorium, tungsten, and ytterbium. On most of the plates lines of the second and third spectra are more in evidence than those of the first, and air lines are prominent. Typical portions of a rhodium plate at 90,500 and 70,000 gauss are shown, and data are given for a number of cerium, rhodium, and ruthenium lines.

THOUGH the study of Zeeman effects affords one of the most powerful aids to the classification of spectra, it has been limited in great degree by the relatively weak magnetic fields which could be maintained over appreciable periods, by the small volume and lack of uniformity of these fields, and by the low intensities of light sources operated in magnetic fields. Kapitza[1] and his co-workers have produced fields up to 320,000 gauss in electromagnets, but these fields remained constant for only about 0.01 second, and were used to photograph Zeeman effects of very strong lines in simple spectra only. Jacquinot[2] and various colleagues have used the large Bellevue electromagnet for Zeeman effect studies, but the strongest fields used were apparently not over 65,800 gauss, 50,000 gauss being the usual value. Most of the Zeeman effect studies reported in the literature have involved fields of 43,000 gauss or less, obtainable with commercial iron-core magnets of the Weiss type.

The new type of electromagnet which one of us has designed[3] has been used successfully to resolve Zeeman patterns of complex spectra at fields up to 99,830 gauss, accommodating a bright electric arc with which 5- to 30-minute exposures suffice to give dense spectrograms with gratings of resolving power 100,000 and over. We have thus been able to resolve very complex

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[1] Kapitza, Strelkov and Laurman, Proc. Roy. Soc. **A167**, 1 (1938).

[2] Jacquinot and Belling, Comptes rendus **201**, 778 (1935).

[3] F. Bitter, Rev. Sci. Inst. **10**, 373 (1939).

patterns, patterns arising from transitions between terms having nearly equal g values, and patterns lying at short wave-lengths. This last is of particular importance, for the wave-length splitting of a line at 2000A is only one-ninth that of a similar line at 6000A.

THE MAGNET

The magnet, which is shown in Fig. 1 in position before the spectrographs, has been described in detail in another paper,[3] where it may be identified as magnet No. 3. It consists of a coil composed of 200 turns of copper strip through which currents up to 10,000 amp. can be sent continuously, enclosed in a bronze jacket. Heat is removed by water which flows past the coil at the rate of 800 gallons per minute. A 1700-kilowatt motor-generator set furnishes d.c. power at voltages up to 170. Various safety devices are provided to insure that the magnet will be properly cooled during operation, and an operator who controls the current through the magnet can keep the field-strength constant to within ±0.1 percent for hours on end.

When first assembled the magnet gave 100,000 gauss on full power, but this field fell gradually to 90,000 gauss during 20 hours of operation. On disassembling the coil it was found that electrolytic deposition between successive turns had partially short-circuited them. Improved internal insulation has been installed to offset or at least delay this deterioration.

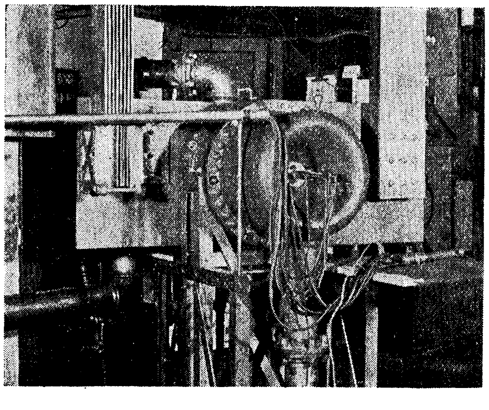

FIG. 1. The electromagnet mounted in position before two spectrographs. Currents up to 10,000 amperes are brought to the solenoid through the bus bars at left and right, while water for cooling passes through the 4-inch pipes which enter the case from above and below. One arc, with its rubber tubes carrying air and water for cooling, is in position; a spare arc, ready to be substituted quickly for the one in the coil, rests on the shelf at the right.

THE LIGHT SOURCE

The central tube of the solenoid has an internal diameter of 3 cm and the field is constant to 1 percent over a length of 4 cm of the tube. This much greater volume of uniform flux than has been available hitherto made possible the design of a new form of arc holder, in which the arc stream could be sent parallel to the lines of force. This holder was mounted in an inner tube which would slide into the solenoid tube from one end. A central water-cooled insulated tube carries the current to one electrode; the arc is struck between this and another electrode colinear with the first, which is mounted in a holder fastened to the grounded outside of the inner tube. To conserve space both electrodes are offset from the axis of the tube, and a small crystal-quartz right-angle prism is mounted so as to throw light from the arc axially out the end of the tube toward the spectrographs. This prism is mounted on a second draw-tube which enters the solenoid tube from the end through which the light is sent, so that it can be withdrawn for rapid cleaning without disturbing the arc. A jet of air blown between the arc and the prism keeps this cool and clean for several minutes of operation, and a spare tube-and-prism unit is kept available for quick replacement.

Since it was desired to study rare earths and other elements which are most conveniently obtained as powdered salts, a new technique was necessary to obtain electrodes which could be burned in the horizontal arc. Professor John Wulff compressed mixtures of 20 percent of the desired salt and 80 percent silver powder, and produced electrodes which can be machined and held in ordinary holders. Electrodes of $\frac{1}{8}$-inch diameter are used, with currents of 4 amperes.

Even with its air or nitrogen blast in operation the arc is so stable that its holder can be moved rapidly through the air without affecting the steadiness of the arc. The arc can be inserted into the solenoid without going out only if the field is off; once in the uniform field, it can be struck at will by turning a knurled rim on the

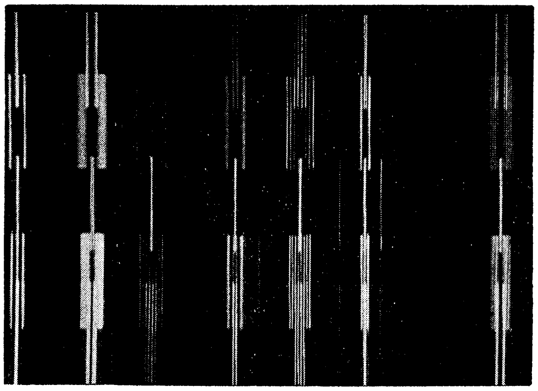

FIG. 2. Portions of the spectrum of rhodium in the region 3500 to 3460A. The spectra in order from the top represent: *p* component, 90,500 gauss; *s* component, same field; no field; *s* component, 70,000 gauss; *p* component, same field.

arc tube to advance and retract the live electrode. It then burns quietly and continuously when the arc column is established exactly parallel to the lines of force; if the arc stream starts flowing at an angle to the field a frittering noise is produced, probably due to whipping of the arc back and forth, and the brightness of the arc is diminished. Under these conditions most of the spectrum lines correspond to the spectra of singly- and doubly-ionized atoms, the lines from neutral atoms being very weak. When the arc burns quietly it is more brilliant than when the field is off.

OPTICAL ARRANGEMENTS

On account of the large power consumption of the magnet it was desired to shorten runs as much as possible, and arrangements were made to send light from the one arc simultaneously into three 35-foot concave diffraction-grating spectrographs. The right-angle prism inside the solenoid was cut with its crystalline axis parallel to its hypotenuse. The light which is sent through this, after leaving the tube, passes through a 2-inch Rochon prism of crystal quartz, transparent to 2000A, and through a quartz-fluorite achromat of 4-cm diameter and 50-cm focal length, which focuses the two polarized components of the light as twin images of the source magnified threefold and separated by about 1.5 cm. One of these is sent directly through the slit of one grating, while that part of the image which does not pass through the slit is reflected from an aluminized plane mirror to a large glass achromat which focuses it on the slit of another grating spectrograph. The second image is reflected from an aluminized plane mirror to an aluminized concave mirror, which focuses it on the slit of a third spectrograph. By rotating the Rochon prism about a horizontal axis the two polarized components of the light can be interchanged.

One component is photographed in the first order of a fairly rapid 35-foot grating, set with its normal at 3500A, and covering the range 2000 to 4300A with a dispersion of 0.8A/mm. At the same time the visible portion of this component can be photographed with a stigmatically mounted 35-foot grating, covering the range 4300 to 8000A with a dispersion of 3.3A/mm. The second component is simultaneously photographed with a third concave grating having its normal at 6000A, giving the range 2500 to 8000A at 0.8A/mm and 2000 to 4000A at 0.4A/mm. The relative speeds of these gratings are approximately as 4 : 30 : 1. In the second exposure the two components are interchanged. Since photographic plates are much slower at wavelengths above 4300A than between 2500 and

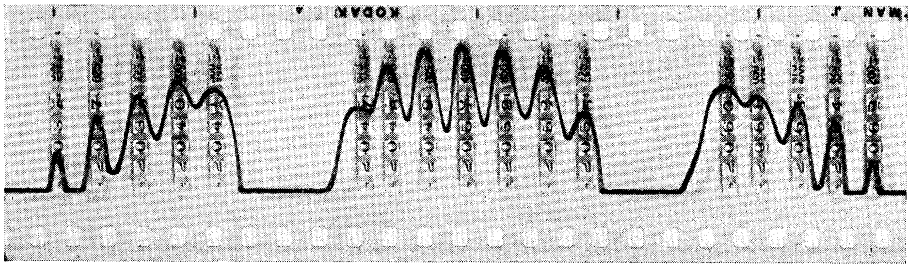

FIG. 3. Section of a record from the automatic comparator, giving density trace and wavelengths for the Zeeman pattern at 89,000 gauss of the europium line 4205.046A.

TABLE I. *Zeeman patterns for cerium II.*

WAVE-LENGTH	INTENSITY	PATTERN	$J1$ $J2$	$g1$ $g2$	COMBINATION BETWEEN TERMS
4202.944	40	(0.084) (0.249) (0.432) 0.637 0.842 1.002 1.171 1.279	2½ 3½	0.732 0.904	18 115
4135.443	20*l*	(0.040) (0.137) (0.241) 0.599 0.689 0.786 0.887 0.983	2½ 2½	0.740 0.836	18 230
4101.772	35	(—) (—) (0.178) (0.290) (0.526) (0.643) (0.761) 0.472 0.594 0.700 0.813 0.927 1.054 1.173 1.285 1.407 1.519 1.623 1.740 1.855	6½ 6½	1.225 1.108	$^4H_{6\frac{1}{2}}$ $^2I_{6\frac{1}{2}}$
3923.109	15	(—) (0.167) (0.286) 0.541 0.661 0.778	2½ 2½	0.723 0.837	18 152
3896.804	35	(0.154) (0.474) (0.774) 0.887 1.193 1.503 1.807	2½ 3½	0.728 1.036	18 127
3442.380	25	(0.096) (0.276) (0.457) 0.457 0.638 0.823 1.045	2½ 2½	0.731 0.915	18 142
3341.868	40	(0.399) (0.659) 0.336 0.595 0.878	2½ 2½	0.730 1.145	18 147
3314.721	25	(0) 0.947	— —	— —	14 141
3314.721	25	(—) (0.433) (0.682) (0.960) 0.204 0.461 0.729 — 1.271 1.551 1.814	3½ 3½	0.868 1.138	15 147
3286.029	18	(0.224) (0.597) (0.990) 0.528 0.933 1.325 1.699	2½ 3½	0.730 1.128	18 149

TABLE II. *Zeeman patterns for rhodium I.*

WAVE-LENGTH	INTENSITY	PATTERN	$J1$ $J2$	$g1$ $g2$	COMBINATION BETWEEN TERMS
3984.40	25	(—) (0.185) 1.392 1.513 1.636	1½ 1½	1.571 1.453	$^4P_{1\frac{1}{2}}$ $^4P_{1\frac{1}{2}}$
3942.716	60	(0.241) 1.332 1.815	1½ ½	1.573 2.657	$^4P_{1\frac{1}{2}}$ $^4P_{\frac{1}{2}}$
3748.217	200	(0.210) (0.624) 0.517 0.934 1.358 1.782	1½ 2½	1.568 1.147	$^4P_{1\frac{1}{2}}$ $^4D_{2\frac{1}{2}}$
3674.765	10	(0.722) 0.485 1.929	½ 1½	2.652 1.208	$^4P_{\frac{1}{2}}$ 4
3605.863	25	(0.240) (0.671) 0.914 1.353 1.795	1½ 1½	1.578 1.130	$^4P_{1\frac{1}{2}}$ $^4D_{1\frac{1}{2}}$
3583.528	10	(0.177) (0.551) 1.024 1.393 1.763	1½ 1½	1.578 1.262	$^4P_{1\frac{1}{2}}$ 9
3541.912	50	(0.695) 0.567 1.957	½ 1½	2.652 1.262	$^4P_{\frac{1}{2}}$ 9
3525.658	50	(0.145) (0.423) 1.146 1.436 1.716	1½ 1½	1.574 1.291	$^4P_{1\frac{1}{2}}$ 5
3505.409	30	(0.583) 0.917 2.072	1½ ½	1.495 2.650	11 $^4P_{\frac{1}{2}}$
3469.624	100	(0.127) (0.379) 0.940 1.193 1.447 1.692	2½ 1½	1.318 1.570	8 $^4P_{1\frac{1}{2}}$
3457.071	100	(0.156) (0.468) 1.106 1.417 1.732	1½ 1½	1.575 1.209	$^4P_{1\frac{1}{2}}$ 4
3344.198	100	(0.710) 0.520 1.950	1½ ½	1.235 2.659	19 $^4P_{\frac{1}{2}}$

TABLE III. *Zeeman patterns for ruthenium I.*

WAVE-LENGTH	INTENSITY	PATTERN	$J1$ $J2$	$g1$ $g2$	COMBINATION BETWEEN TERMS
4032.205	20	(0) (0.429) (0.844)	2	0.987	$^5F_2$
		— 0.972 1.419 1.859 2.275	3	1.417	$^5D_3$
3882.006	12	(0.328) (0.655)	2	1.000	$^5F_2$
		0.682 1.013 1.323 1.637	2	1.328	$^5D_2$
3819.033	50	(0) (0.297) (0.591)	2	0.999	$^5F_2$
		0.682 1.001 1.299 1.589 1.890	3	1.295	$^5F_3$
3742.280	70	(0.169) (0.309)	2	0.994	$^5F_2$
		0.847 0.994 1.142 1.306	2	1.150	$^5F_2$
3579.768	3	(0) (0.248) (0.497)	3	1.247	$^5F_3$
		0.755 1.001 1.243 1.496	2	1.494	17
3539.369	60	(0.624) (1.247)	2	1.001	$^5F_2$
		0.378 1.004 1.623	2	0.378	$^5G_2$
3528.683	60	(0) (0.202) (0.398)	2	1.013	$^5F_2$
		0.823 1.010 1.213 1.407 1.607	3	1.211	16
3514.488	70	(0) (0.313) (0.622) (0.921)	3	1.248	$^5F_3$
		0.327 0.634 0.937 1.248 1.554 1.861	3	0.940	$^5G_3$
3430.772	70	(0) (0.123) (0.265)	2	1.004	$^5F_2$
		0.619 0.743 0.875 1.004 —	3	0.875	$^3G_3$
3417.353	1	(0) (0.136) (0.259) (0.391)	3	1.230	$^5F_3$
		0.724 0.848 0.970 1.106 1.239 1.347 1.482	4	1.101	15
3223.274	60	(0) (0.477)	2	0.976	$^5F_2$
		— — 1.448 1.948	2	1.457	14
3189.976	50	(0.233) (0.457) (0.739)	3	1.266	$^5F_3$
		1.048 1.247 1.529 1.739 1.947	3	1.501	13
3186.044	80	(0) (0.520)	2	0.994	$^5F_2$
		0.482 0.998 1.503	1	1.508	12
3020.882	60	(0) (0.268) (0.540)	2	1.007	$^5F_2$
		0.741 1.002 1.289 1.560 1.821	3	1.280	11
2905.650	50	(0) (0.480) (0.939)	2	0.986	$^5F_2$
		0.532 1.003 1.449 1.932 2.344	2	1.452	10

4300A, and since less resolution and dispersion are needed for the patterns of longer wave-length, resolution may well be sacrificed for speed in the visible region.

SPECTRA STUDIED

From 12 to 21 plates each 20 inches long are exposed simultaneously to the spectrum from 2000 to 8000A. Exposures have ranged from five minutes to half an hour, and five exposures are usually taken on each set of plates. The two strongest silver lines usually produce over-exposed Zeeman patterns in 1 minute. Runs have been made on cerium, columbium, erbium, europium, gadolinium, iron, neodymium, praseodymium, rhodium, ruthenium, thorium, thulium, tungsten, and ytterbium. On most of the plates the second and third spectra are more in evidence than the first, and air lines are prominent.

Typical portions of a rhodium plate are shown in Fig. 2. In Fig. 3 is shown a pattern of a europium line as traced and measured on the automatic density comparator.[4] This instrument is particularly useful with Zeeman patterns, for wave-lengths or wave numbers of hundreds of patterns on one plate, some split into as many as 27 components, can be recorded to seven-figure

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[4] G. R. Harrison, J. Opt. Soc. Am. **25**, 169 (1935).

precision in two minutes, with results for resolved lines which are more precise than those obtained by ordinary methods.

RESULTS OBTAINED

The data for the various elements are being used in the classification of their respective spectra, and will be published in full separately. Typical results for cerium, rhodium, and ruthenium are recorded in Tables I, II, and III, in which column 1 gives the wave-length as given by the M.I.T. Tables,[5] column 2 the arc intensity from the same source, column 3 the Zeeman pattern in terms of the normal separation, column 4 the J values of the combining terms, column 5 the g values of the combining terms, and column 6 the term combination.

Data have been included in the tables whereby the g values of certain levels are determined from six or more lines. Average g values are found to be consistent within 0.003 unit, and can probably be determined at wave-lengths longer than 3000A to within 0.1 percent. The principal uncertainties in the g values arise from uncertainties in the determination of field intensities, which have thus far been obtained only from lines showing the normal Zeeman effect.

Of particular interest in the cerium data are the confirmations of unusual classifications of lines given by Albertson and Harrison[6] in Ce II. The line Ce 3314.732A was classified as two independent transitions; under the influence of the field it broke up into two patterns which correspond to the proper pairs of J values. The line Ce 4101.772 was classified as $6\frac{1}{2}-6\frac{1}{2}$, and is shown by its pattern to be ${}^4H_{6\frac{1}{2}}-{}^2I_{6\frac{1}{2}}$. Hundreds of other line classifications have been confirmed and extended.

ACKNOWLEDGMENTS

We are grateful to Dr. A. R. Kaufmann for assisting in the operation of the magnet during the first exposures, when its behavior was uncertain, and to Julius Molnar and Henry Rich for aiding in the operation of the spectrographs. The work has been greatly assisted by grants from the Penrose Fund of the American Philosophical Society for the operation of the magnet, from the Rumford Fund of the American Academy of Arts and Sciences for the provision of the chemicals whose spectra were studied, and from the Hale Spectroscopic Fund for apparatus.

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[5] *M. I. T. Wavelength Tables* (John Wiley & Sons, New York, 1939).

[6] W. Albertson and G. R. Harrison, Phys. Rev. **52**, 1209 (1937).

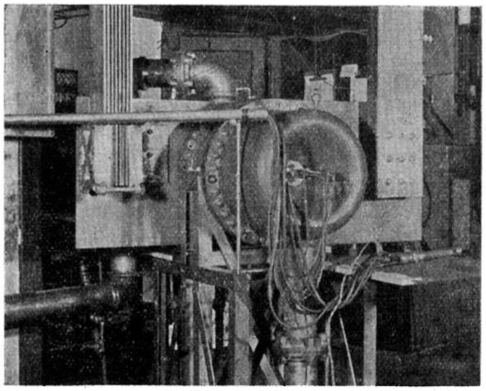
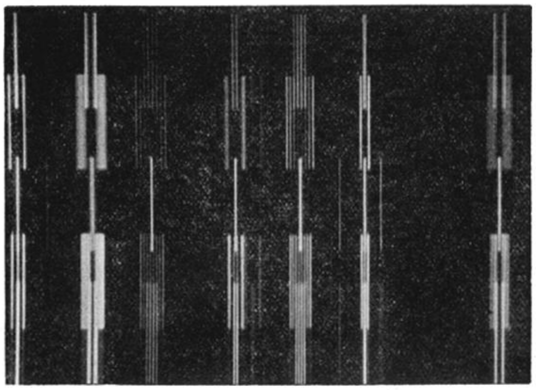


Fig. 1. The electromagnet mounted in position before two spectrographs. Currents up to 10,000 amperes are brought to the solenoid through the bus bars at left and right, while water for cooling passes through the 4-inch pipes which enter the case from above and below. One arc, with its rubber tubes carrying air and water for cooling, is in position; a spare arc, ready to be substituted quickly for the one in the coil, rests on the shelf at the right.



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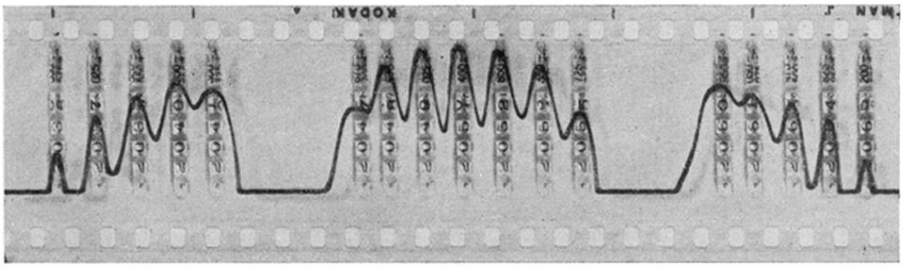

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