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B C FAWCETT
M GALANTI
N J PEACOCK

CULHAM LABORATORY
Abingdon Berkshire

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SPECTRAL CLASSIFICATIONS IN THE Fe XIX TO Fe XXIII ISOELECTRONIC SEQUENCES

B C Fawcett,[†] M Galanti[‡] and N J Peacock

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ABSTRACT

Emission lines are classified belonging to $2s^22p^n$-$2s2p^{n+1}$ transition arrays in the ions Ti XVII, V XVII to XX, Mn XVIII, Mn XIX, Fe XIX and Fe XX. The source of these ions is the plasma produced at metallic surfaces irradiated with a neodymium laser beam with a focused power density in the range of 10^{12} to 10^{13} watts per sq cm at the target surface. The data reported can be applied to the interpretation of solar flare spectra.

[†] Science Research Council, Astrophysics Research Division of RSRS, Culham Laboratory.

[‡] ESRO Fellow, on attachment from Imperial College, London.

UKAEA Research Group,
Culham Laboratory,
Abingdon,
Berks.

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1. INTRODUCTION

Simple modifications to the optics of a neodymium laser which do not involve the use of Faraday or electro-optical isolators have permitted the generation of laser produced plasmas with a 2 GW laser beam focused onto a 120 micron focal spot area on a metal target. This laser light intensity is sufficiently high to produce helium-like ions at least as high as magnesium XI (Peacock, Hobby, Galanti, 1973) and in this study ions isoelectronic with Fe XIX to Fe XXIV in the first long period. Emission lines belonging to the $2s^2 2p^n - 2s2p^{n+1}$ transition arrays in Ti XVII, V XVII to XX, Mn XVIII, Mn XIX, Fe XIX and Fe XX have been subsequently identified. These ions are rather more highly ionised than have been reported previously (Fawcett 1971a,b) and allow isoelectronic extrapolation through to energy levels in ions which are of astrophysical interest. To enable the delivery of this laser power to the plasma it was necessary to solve the problems arising from self-oscillation of the amplifier stages and backscatter of the laser light from the plasma formed at the target. Both of these problems occur with a neodymium laser at incident light intensities greater than about 10^{12} watts per sq cm.

2. EXPERIMENTAL TECHNIQUES

The neodymium laser and the arrangement of apparatus for the acquisition of spectrograms have been described elsewhere (Galanti and Peacock 1973). The two difficulties mentioned above associated with the high incident light intensities are now discussed more fully along with the methods applied to overcome them. The first is that of backscatter due to reflection at the plasma which occurs at the critical density for light absorption which is $10^{21}cm^{-3}$ for a 1.06 micron laser beam. Light from the main laser output pulse can after reflection be amplified in the laser rods and then cause catastrophic damage to the optical components in the oscillator. The oscillator section was therefore protected by inserting an air-breakdown fuse, formed by a telescopic lens system of two convex lenses, between the oscillator and first amplifier. The lenses were arranged in such a way that the forward travelling pulse had insufficient power to break down the air at their focus whereas the backwards reflected pulse caused air breakdown and was absorbed. The second problem occurs in the period before the laser output pulse but after the flash tubes have optically pumped the laser rods. The target and focusing lens combination behaves like a mirror with a small reflectivity which is nevertheless adequate to cause the entire amplifier oscillator system to free-lase. This condition is generally found with neodymium lasers at power levels higher than 1 GW. In consequence the prelasing depletes the population inversion in the laser rods so that when the laser is Q switched multi-gigawatt power outputs are not achieved. To surmount this problem a saturable dye, Eastman A9740, was inserted after the first amplifier of the three-amplifier system. This had the effect of impeding the optical path between the oscillator and target until the main laser pulse bleached the dye. Using these components the peak pulse intensity to background ratio, ie the contrast, is better than 10^5. For higher powers optical isolators such as a Faraday rotator are recommended. In order to avoid the light pulse reflected from the target entering the laser during the output pulse a distance of 3 metres was allowed between the last amplifier and the focusing lens. The target was situated 0.5 cm in front of the entrance slit of a two metre grazing incidence spectrograph. The grating had 600 lines per mm and spectrograms were recorded on Ilford Q2 plates and measured with an Abbe Zeiss comparator. Wavelength calculations were performed with a computer programme described by Fawcett et al. (1973). Second order Ti XII lines were used as wavelength standards. The resultant wavelength accuracy was ± 0.02 Å.

A plasma temperature of 350 eV has been measured from the Lyman continuum at the surface of a PTFE target irradiated with an incident light flux intensity of 2×10^{12} watts per sq cm (Galanti and Peacock 1974). With a power density of nearly 10^{13} watts per sq cm as used here H-like Mg XII can be produced at a magnesium surface and the corresponding temperature has been estimated at 450 eV. These plasma temperatures are sufficiently high to generate the spectra of interest in this paper but the temperatures existing in these heavier element plasmas could be different.

3. SPECTRAL CLASSIFICATIONS

Recently Feldman et al. (1973) classified spectra of Fe XVIII and Fe XIX which were radiated from laser produced plasmas. The observations reported in this paper include in addition lines of Fe XX which are listed in table 1 along with new identifications of isoelectronic V XVII and Mn XIX lines. The spectrogram which is reproduced in the illustration also included clear reproductions of the lines reported by Feldman et al. and these new measurements are in complete agreement with theirs. A further Fe XIV line which decays to the high $2s2p^5\ {}^1P$ energy level is listed in table 2 with isoelectronic identifications along the sequence. Table 3 lists Mn XVIII identifications isoelectronic with those of Fe XIX reported by Feldman et al.

Lines of Fe XXI were not present on the spectrograms but better predictions of their wavelengths can now be made on the basis of extrapolations from the new wavelengths and identifications of Ti XVII and V XVIII emission lines listed in table 4. Similarly the state of progress in the Fe XXII isoelectronic sequence is considerably advanced with the identification of the V XIX lines listed in table 5. Furthermore, the $2s^2\ {}^1S_o$-$2s2p\ {}^1P_1$ VXX resonance line is observed at 160.0 Å. Previously the highest ionisation stages for these transitions were reported in Ar XIV and Ar XV. The V XIX and V XX lines were emitted when the laser output power was increased to 4 GW.

The identifications were made on the basis of isoelectronic extrapolations from existing data tabulated by Fawcett (1971a,b).

4. CONCLUSION

This paper clarifies some of the problems involved in feeding the output of high power lasers into a laser produced plasma and offers a simple solution in the intermediate power range which contrasts with the elaborate introduction of the Faraday rotators. The new data presented regarding highly ionised Fe XIX to XXIII iron spectra should aid the interpretation of the solar flare spectrograms in the spectral region between 80 and 140 Å once adequate solar flare records are available.

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TABLE 1

CLASSIFIED LINES OF V XVII, Mn XIX and Fe XX

Combination	V XVII		Mn XIX		Fe XX	
	Int	Wavelength Å	Int	Wavelength Å	Int	Wavelength Å
$2s^22p^3-2s2p^4$						
$^2D-^2P$						
$2\frac{1}{2}-1\frac{1}{2}$	6	111.27 F	3	99.18	3	93.80
$1\frac{1}{2}-\frac{1}{2}$	4	102.84 F			1	83.94 T
$1\frac{1}{2}-1\frac{1}{2}$	2	108.97				
$^2P-^2P$						
$\frac{1}{2}-\frac{1}{2}$	2	113.40				
$1\frac{1}{2}-\frac{1}{2}$	2B	117.24 F				
$\frac{1}{2}-1\frac{1}{2}$	3	120.86 F				
$1\frac{1}{2}-1\frac{1}{2}$	3B	125.26				
$^2D-^2D$						
$2\frac{1}{2}-2\frac{1}{2}$	8	136.45 F	5	120.47	5	113.34
$1\frac{1}{2}-1\frac{1}{2}$	7	134.01 F	4	117.76	4	110.63
$^2P-^2D$						
$\frac{1}{2}-1\frac{1}{2}$	1	152.53				
$1\frac{1}{2}-2\frac{1}{2}$	3	158.13	1	142.74	2	136.34
$^4S-^4P$						
$1\frac{1}{2}-\frac{1}{2}$	1	146.72				
$1\frac{1}{2}-1\frac{1}{2}$	4	150.03 F		130.60	4	121.83
$1\frac{1}{2}-2\frac{1}{2}$	6	159.30 F		141.07	5b	132.8 T
$2s2p^4-2p^5$						
$^2D-^2P$						
$2\frac{1}{2}-1\frac{1}{2}$	3	130.98				
$1\frac{1}{2}-\frac{1}{2}$	2	120.33				
$^2P-^2P$						
$1\frac{1}{2}-1\frac{1}{2}$	2	167.37				
$\frac{1}{2}-\frac{1}{2}$	1	151.69				

F = Fawcett 1971
T = Tentative
b = Blend
Accuracy ± 0.02 Å

TABLE 2

OBSERVED WAVELENGTHS OF $2s2p^5\ {}^1P_1 - 2p^6\ {}^1S_0$ EMISSION LINES

Ion	Å
Mg V	376.665
Al VI	328.67
Si VII	291.22
P VIII	261.05K
S IX	236.34K
K XII	182.74
Ca XIII	169.49K
Sc XIV	157.06B
Ti XV	147.39K
V XVI	138.17
Mn XVIII	122.29
Fe XIX	115.42

K = Kononov (private communication)

TABLE 3

CLASSIFIED LINES OF Mn XVIII

Combination	Int	Wavelength Å
$2s^2 2p^4 - 2s2p^5$		
$^3P - ^3P$		
2-2	9	115.38F
1-1	3	118.25
2-1	6	108.76F
1-2	5	126.12
0-1	3	117.25
1-0	4	113.31
$^1D - ^1P$		
2-1	7	96.23F
$^1S - ^1P$	2	111.39

TABLE 4

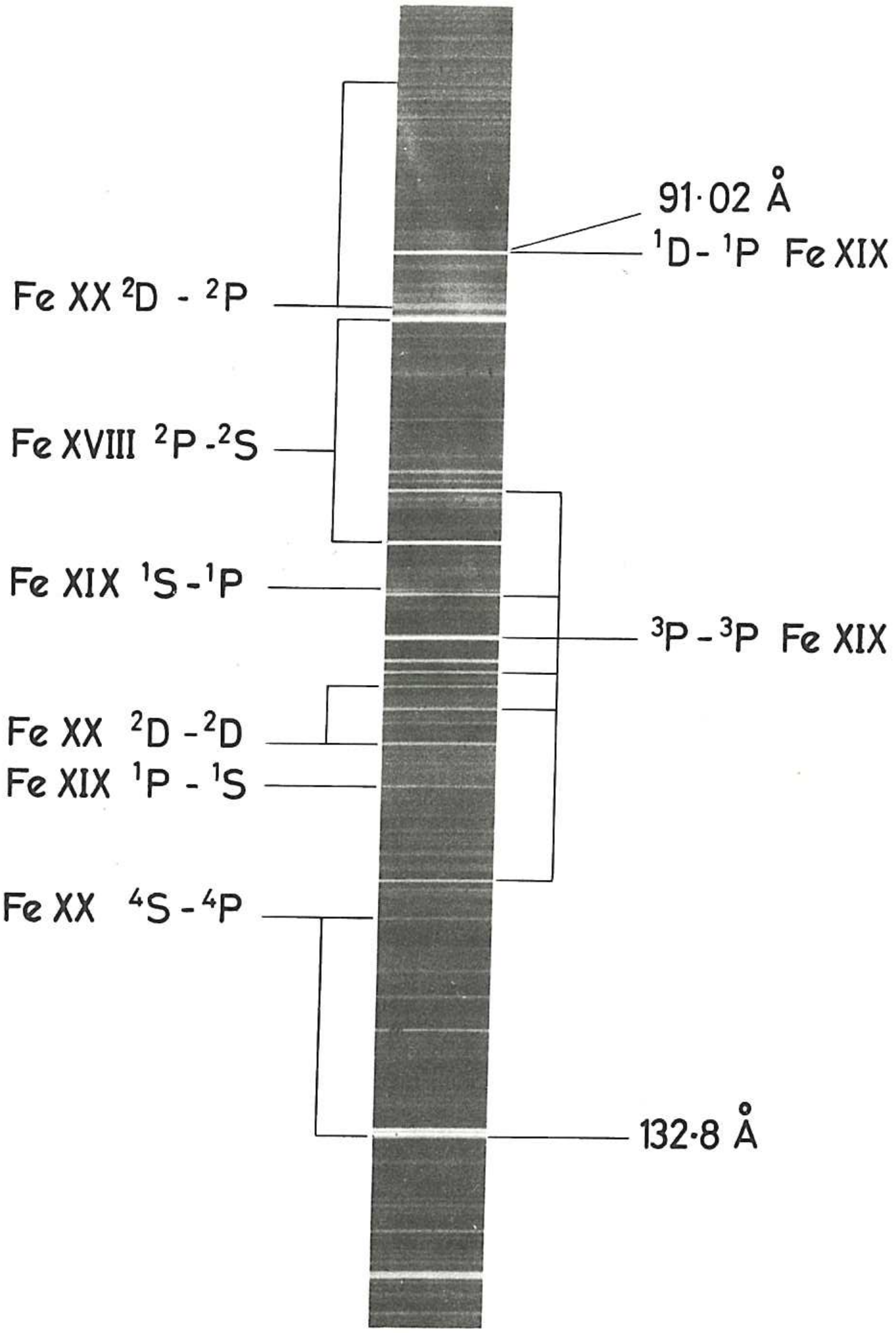
CLASSIFIED LINES OF Ti XVII and V XVIII ISOELECTRONIC WITH Fe XXI

Combination	Ti XVII		V XVIII	
	Int.	Wavelength Å	Int.	Wavelength Å
$2s^2 2p^2 - 2s2p^3$				
$^3P - ^3D$				
2-3	7	188.37	5	176.41
1-2	5	182.11	3	170.67
0-1	4	176.27	1	165.35
$^3P - ^3P$				
0-1			1	136.00
2-1			1	149.81
2-2	7	158.43	5	148.11
1-0	2	154.09	1	143.84
1-1	2	153.50	1	143.39
1-2	1	152.10	1	141.73
$^3P - ^3S$				
2-1	7	127.77	5	120.60
1-1	5	123.65	3b	116.33
0-1	3	119.30		111.42
$^1D - ^1D$				
2-2	8	141.92	6	133.78
$^1D - ^1P$				
2-1	7	124.56	5b	117.22
$^1S - ^1P$				
0-1	4	142.57	3	134.1 B

TABLE 5

CLASSIFIED LINES OF V XIX ISOELECTRONIC WITH Fe XXII

Combination	Int	Wavelength Å
$2s^2 2p - 2s2p^2$		
$^2P - ^2P$		
$\frac{1}{2} - 1\frac{1}{2}$	2	124.63
$\frac{1}{2} - \frac{1}{2}$	2	126.83
$1\frac{1}{2} - 1\frac{1}{2}$	7	126.24
$1\frac{1}{2} - \frac{1}{2}$	4	138.84
$^2P - ^2S$		
$\frac{1}{2} - \frac{1}{2}$	4	139.59
$^2P - ^2D$		
$\frac{1}{2} - 1\frac{1}{2}$	3	164.38
$1\frac{1}{2} - 2\frac{1}{2}$	5	181.81



$2s^2\,2p^n - 2s\,2p^{n+1}$ transitions of Fe XVIII to Fe XX emitted from a plasma generated on an iron surface irradiated with a laser light intensity of 10^{13} watts per sq. cm.