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Hyperfine structure analysis in the intense spectral lines of the neutral Cu atom falling in the 353–809 nm wavelength region using a Fourier transform spectrometer

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ABSTRACT

Hyperfine structure analyses have been performed in the high-resolution spectrum of the neutral copper atom covering the wavelength region of 353–809 nm using Fourier transform spectroscopy. A DC discharge of natural copper produced in a liquid nitrogen cooled hollow cathode lamp used as a light source and a photomultiplier tube as well as Si photodiodes were employed as the light detectors. The hfs studies in 17 transitions of the neutral copper atom originating from 17 energy levels for ^{63}Cu have been reported here. The present investigation has provided the magnetic dipole coupling constant A and electric quadrupole coupling constant B for the first time for the following 6 even-parity levels lying at 49,935, 49,942 cm^{-1}, of 3d^{10}4d configuration, 52,848 cm^{-1} of 3d^{10}6 s configuration, 55,387, 55,391 cm^{-1} 3d^{10}5d configuration and 71,978 cm^{-1} of 3d^{10}4s4d configuration. The sign convention of the previously-reported hfs A value amounting to 1920 MHz for the level at 44,963 cm^{-1} of 3d^{9}4s4p configuration has been revised to −1920 MHz. Measurements reported earlier of A and B hfs constants for the 11 odd-parity energy levels also have been confirmed.

1. Introduction

Conventional high-resolution studies like isotope shift (IS) [1] and hyperfine structure (hfs) splitting [2] in the spectrum of neutral copper atom (Cu I) were performed in large scale using a Fabry Perot spectrometer (FPS). Atomic beam magnetic resonance methods have been employed to study hfs in the ground states [3] and in the metastable states [4] of ^{63}Cu and ^{65}Cu isotopes. A level-crossing technique [5] has been applied to calculate hfs splitting of the 3d^{10}4p $^2P_{3/2}$ level under the influence of configuration interaction effect. The LS coupling and configuration interaction parameters stated were equally important while calculating hfs 'A' and 'B' constants in the levels of 3d^{9}4s4p, 3d^{10}4p and 3d^{10}5p configurations [6]. Interpretation of experimental relative oscillator strength in 11 UV resonance lines [7] have been carried out with the help of previous hfs and IS data [6] recorded in the levels of 3d^{9}4s4p, 3d^{10}4p and 3d^{10}5p configurations. After the invention of lasers, Doppler-free laser spectroscopy [8] has been used for the first time to study the two strong lasing transitions at 510.5 nm and 578.2 nm.

There were a few more hfs studies performed mostly in the two strong lasing transitions at 510. 5 nm and 578.2 nm employing different laser spectroscopy techniques [9–13]. hfs Study in the 3d^{10}4p $^2P_{3/2}$ level has been performed again using the pulsed level-crossing spectroscopy [14] technique at short wavelength, 202.4 nm, using a Rhodamine dye laser. Relativistic Hartree–Fock [15] and Dirac–Fock multi-configuration [16] calculations of hfs A

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Table 1
List of spectral lines of Cu I in which hfs have been recorded for ^{63}Cu on the FTS using liquid nitrogen cooled HCL. The A and B hfs constants have been derived in the present studies by least square peak fitting procedure. The unit of the wavelength is nm, and that of intensity is arbitrary units (arb. units) whereas the energy levels were expressed in cm^{-1}. The transitions have been referred from [37] whereas their energy levels listed in columns 4 and 6 taken from [38]. $\sigma_{std,i}$: Estimated enrgy level difference, $K_i=(\sigma_{std,i})/(\sigma_{obs,i})-1$, $\sigma_{Corr}=\sigma_{FTS}(1+K)$, and $\Delta\sigma=(\sigma_{Corr}-\sigma_{std,i})$, all in cm^{-1}.

Intensity [37] (arb. units)	Wavelength [37] (nm)	S/N ratio	Energy levels (cm^{-1}) [38]				cm^{-1}		
			Odd parity	J	Even parity	J	$\sigma_{std,i}$ [37]	σ_{Corr}	$\Delta\sigma$
2000	353.0383	25	41,562.895	5/2	13,245.423	3/2	28,317.472	28,317.7735	0.2962
250h	370.0536	9	44,963.223	7/2	71,978.700	9/2	27,015.477	27,015.317698	−0.1593
1250	402.2629	10	30,535.302	1/2	55,387.668	3/2	24,852.366	24,852.28007	−0.085
2000	406.2641	10	30,783.686	3/2	55,391.292	5/2	24,607.606	24,607.52346	−0.08254
950	427.5107	20	39,018.652	5/2	62,403.320	7/2	23,384.668	23,384.73838	0.0704
500	448.0350	30	30,535.302	1/2	52,848.749	1/2	22,313.447	22,313.448	0.001
800h	453.0785	5	30,783.686	3/2	52,848.749	1/2	22,065.063	22,065.19752	0.1345
2000	465.1124	9	40,909.138	9/2	62,403.320	7/2	21,494.182	21,494.23	0.048
1500	510.5541	30	30,783.686	3/2	11,202.565	5/2	19,581.121	19,581.14219	0.0212
2000	515.3235	35	30,535.302	1/2	49,935.200	3/2	19,399.898	19,399.90478	0.00678
2500	521.8202	75	30,783.686	3/2	49,942.057	5/2	19,158.371	19,158.40927	+0.03287
500	522.0070	10	30,783.686	3/2	49,935.200	3/2	19,151.514	19,151.59312	+0.07912
1650	529.2517	50	43,513.950	7/2	62,403.320	7/2	18,889.37	18,889.35597	−0.01403
1500	570.0240	10	30,783.686	3/2	13,245.423	3/2	17,338.263	17,538.22581	−0.03719
1500	578.2132	50	30,535.302	1/2	13,245.423	3/2	17,289.879	17,289.8597	−0.0193
1500	793.3130	50	30,535.302	1/2	43,137.209	1/2	12,601.907	12,601.8802	−0.0263
2000	809.2634	65	30,783.686	3/2	43,137.209	1/2	12,353.523	12,353.51473	−0.00827

Table 2
List of Ne I spectral lines [35] observed in the present work and employed to calibrate the Cu I spectrum. Unit employed for wavenumber is cm^{-1}, and for intensity is arb. units, and σ_{Std}=wavenumber referred from [35], σ_{FTS}=observed wavenumber, σ_{Corr}=corrected wavenumber, W: full width at half maximum (FWHM) in cm^{-1}.

Wavelength (Å)	Intensity (arb. units)	S/N	Wavenumber[a] (cm^{-1})						
			σ_{Std} [35]	σ_{FTS}	$\Delta\sigma$	W	K	$(1+K)$	σ_{Corr}
3447.7024	2000	48	28,996.5144	28,996.8378	0.3234	0.12856	−1.1153065-5	0.999988846	28,996.51439
3472.5706	5000	35	28,788.8673	28,789.1824	0.3151	0.12585	−1.0945203-5	0.999989054	28,788.86729
3520.4711	10,000	43	28,397.1699	28,397.4669	0.297	0.13108	−1.0458789-5	0.999989541	28,397.16989
3593.5257	5000	42	27,819.8856	27,820.15696	0.27136	0.12622	−9.7541738-6	0.999990245	27,819.88559
3593.6389	3000	23	27,819.0088	27,819.27874	0.26898	0.1208	−9.6686235-6	0.999990331	27,819.00879
4704.3949	15,000	13	21,250.7726	21,250.81694	0.04434	0.06115	−2.0865124-6	0.999997931	21,250.72259
5116.5032	1500	35	19,539.1536	19,539.2075	0.0539	0.0806	−2.7585637-6	0.999997241	19,539.15359
5113.6724	750	11	19,549.9698	19,550.03352	0.06372	0.07588	−3.2593400-6	0.99999674	19,549.96979
5400.5618	20,000	32	18,511.4457	18,511.48238	0.03668	0.08468	−4.5744671-6	0.999998081	18,511.44569
5433.6513	2500	15	18,398.7176	18,398.76391	0.04631	0.07187	−2.5170233-6	0.999997483	18,398.71759
5852.4879	20,000	64	17,082.0155	17,082.04912	0.03362	0.09178	−1.9681518-6	0.999998031	17,082.01549
5881.8952	10,000	42	16,996.6124	16,996.6436	0.0306	0.08478	−1.8003588-6	0.999998199	16,996.61299
5944.8342	5000	97	16,816.6679	16,816.69678	0.02888	0.09312	−1.7173438-6	0.999998282	16,816.66789
5975.5340	6000	74	16,730.2718	16,730.29856	0.02676	0.07453	−1.5994958-6	0.9999984	16,730.27179
5987.9074	1500	23	16,695.7006	16,695.72697	0.02637	0.08951	−1.5794485-6	0.99999842	16,695.70059
6029.9969	10,000	62	16,579.1653	16,579.1914	0.0261	0.07623	−1.5742650-6	0.999998425	16,579.16529
6382.9914	10,000	111	15,662.3058	15,662.32471	0.01891	0.10817	−1.2073573-6	0.999998792	15,662.30579
6506.5281	15,000	55	15,364.9344	15,364.95322	0.01882	0.12828	−1.2248669-6	0.999998775	15,364.93439
6532.8822	1000	80	15,302.9511	15,302.96644	0.01534	0.07891	−1.0024210-6	0.999998997	15302.95109
6598.9529	10,000	44	15,149.7351	15,149.7513	0.0162	0.09326	−1.0693256-6	0.99999893	15,149.73509
7032.4131	85 000	70	14,215.9498	14,215.95853	0.00873	0.12255	−6.14098961-7	0.999999385	14,215.94979
7173.9381	77,000	38	13,935.5042	13,935.50527	0.00107	0.08678	−7.6782295-8	0.999999923	13,935.50419
7245.1666	77,000	99	13,798.5027	13,798.50447	0.00177	0.09506	+1.2827478-7	0.999999871	13,798.50269
7438.8984	60,000	58	13,439.1493	13,439.14726	−0.00204	0.07986	+1.5179532-7	1.000000152	13,439.14929
7535.7741	28,000	53	13,266.3841	13,266.37888	−0.00522	0.07247	+3.9347572-7	1.000000393	13,266.38409
7544.0443	13,000	40	13,251.8407	13,251.83597	−0.00473	0.07228	+3.5693155-7	1.000000357	13,251.84069
7936.9961	1300	48	12,595.7603	12,595.74474	−0.01556	0.07103	+1.2353363-6	1.000001235	12,595.76029
7943.1814	7900	80	12,585.9521	12,585.9367	−0.0154	0.07054	+1.2235864-6	1.000001223	12,585.95209
8300.3258	29,000	52	12,044.4094	12,044.3966	−0.0143	0.06774	+1.1872728-6	1.000001187	12044.40939
8301.557	1900	17	12,042.6221	12,042.60879	−0.01331	0.06417	+1.1052410-6	1.000001105	12,042.62209

[a] All wavenumber values carry (cm^{-1}) units. $K=(\sigma_{Std}/\sigma_{FTS})-1$, and $\sigma_{Corr}=\sigma_{FTS}(1+K)$.