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14*a*. SUB-COMMISSION ON INTENSITY TABLES: REPORT ON TABLES OF *f* VALUES

The necessity of collecting all available oscillator strengths, either determined by experiments or calculated by quantum mechanics, has been repeatedly emphasized in these *Transactions*. A first survey of the literature was published in the report of Commission 36 for the 1948 meeting. Since then, several such tables have been prepared, which apparently will soon provide for this generally felt need.

(*a*) In 1950 appeared the sixth edition of Landolt-Börnstein's *Zahlenwerte und Funktionen*, of which Vol. 1 contains tables of *f* values by Biermann. The tables of absolute values are fairly complete; relative values are quoted for Fe and Ti; for other elements the necessary references are given. Special lists refer to forbidden lines and to molecular bands. Dr Biermann writes that he is still keeping his catalogue up to date in view of further editions.

(*b*) In the book by Allen, *Astrophysical Quantities* (in the Press) about 350 oscillator strengths of astrophysical importance will be collected, 100 of these being components of hydrogen lines.

(*c*) Another list is being prepared by Menzel for the *Smithsonian Physical Tables*.

(*d*) In the new edition of Unsöld's book, now in the Press, a very complete list of references will be communicated, ordered according to the periodic system and mentioning whether the determinations were absolute or relative, experimental or theoretical.

(*e*) Finally, a list is expected to be found in Condon, *Handbook of Physics*, part 7, chap. 3 (in the Press; McGraw Hill).

Although these compilations will be of the greatest use for the astrophysicist, it must be recognized that they do not yet give the whole of the data, critically combined and ready for use. No spectroscopist would be satisfied if instead of tables of spectral lines he had only a list of references or the wave-lengths of 350 selected lines. There is therefore ample opportunity for future work, which should make available all theoretical and

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experimental data from various sources, critically balanced and combined. For the astrophysical investigation, there is also more and more need of other data on the individual spectral lines, which partly determine their strength and their width in cosmic objects: (1) the line broadening and the asymmetry due to the Stark effect; (2) the hyperfine structure. It would be extremely useful if it was possible to collect such quantities, now scattered through the literature.

In this report a review will be given only of the most recent work on *f* values, done since the 1951 I.A.U. meeting, and not always easily accessible, because the publications are distributed between physical and astronomical periodicals. These references have been collected by an active collaboration of the President of Commission 14, of the members of the sub-commission and of other scientists. A small list has been added of Russian determinations of recent years, which seem to be hardly known in the Western countries, and have been quoted mainly from the paper of Mitrofanova.

Theoretical investigations

The very useful paper of Bates and Damgaard, allowing a quick calculation of atomic transitions in first approximation, has been followed by a similar paper of Bates on molecular transitions for all diatomic molecules. By taking as a starting-point the observed spectroscopic constants, the calculation could be made very simple.—Of interest is a sum rule for molecular transitions, due to Ter Haar.—Pasternack, Shortley, Aller, Baker, Menzel and Gottschalk had already shown that calculations assuming the Russell-Saunders coupling can be considerably improved if ***intermediate coupling*** is taken into account, this meaning the interaction between the electron spin with its own orbit. Garstang and others applied the method to other cases and reached a similar success. Still better results can be obtained by considering the ***spin-spin interaction*** between the two electrons and the ***spin-other orbit interaction***; this has been done earlier by Aller, Ufford, van Vleck and Gilmour, and has been applied recently by Garstang (1951) to several atoms and ions. The calculation of the effect of ***configuration interaction*** would give the best results, but at the cost of increased labour. Layzer has recently developed a new method for the problem of configuration mixing and has applied it to some special cases, e.g. to Ca XV.

Menzel and Layzer remark that the energy levels are insensitive to small errors in the wave functions, whereas the *f* values are not. This considerably increases the difficulty in predicting *f* values.

Experimental determinations

An extensive investigation was undertaken by Meggers and his collaborators. They measured under standard conditions the intensities of 30,000 spectral lines, belonging to 70 elements, between 2000 and 9000 Å, and proved that their results did correspond to the multiplet rules and other known *f* values. When published, these determinations will be of great value to the astrophysicist, though they are admittedly rough.

As to the absolute measurements, several methods have been applied which do not require a knowledge of the vapour pressure of elements at high temperatures—the weak point in much of the earlier work.

1. The method of anomalous dispersion of Rozhdestvenski was taken up with remarkable success by his pupils and applied even to elements of small volatility.
2. Stephenson measured the magnetic rotation.
3. Kopfermann and Wessel applied the method of the atomic beam to the important case of iron. The absolute values thus found are about three times greater than those previously assumed; a factor of that order had already been suspected earlier. The same method is now being applied by R. B. King to Fe, Cr and Cu.
4. Huldt and Lagerquist spray in a flame known quantities of a salt.
5. In the Physical Laboratories at Kiel and at Erlangen, an electric arc is stabilized

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by the whirling motion of the surrounding gas; several liquids may be injected tangentially. The arc is observed end-on, and its temperature may reach 50,000°.

6. At the Michigan Observatory, the luminous shock tube is used for the investigation of f values, in particular for Ne I.

For the astrophysically important elements Fe, Mn, Ni and Cr, absolute probabilities have now been determined. It is to be hoped that soon measurements will be obtained for Co, Ti and V, and for the ionized atoms of these seven elements.

Astrophysical determinations

A derivation of f values from curves of growth has been tried several times. The results are valuable, since they often refer to lines which could be investigated only with difficulty in a laboratory, but they may show considerable mean errors, for the line formation in a stellar atmosphere is a very complicated phenomenon.

A paper by Aller and his collaborators gives values for Fe II, Ti II, Cr II and some other ionized elements, derived from the spectrum of XX Oph. (1954, in the Press).

Nomenclature

Data on transition probability are expressed in various ways: A, f, gf, S. Menzel and Layzer suggest using as a rule the line-strength S (definition, cf. Condon and Shortley, p. 98). This is closely related to the other quantities mentioned above; it has the advantages: (1) to be the most useful from a theoretical point of view; (2) to satisfy certain sum rules; (3) to be symmetric in the initial and final levels.

Others object that transitions with comparable line-strengths have very different intensities, if electric dipole, electric quadrupole and magnetic dipole radiation are compared. They prefer the products gf, which are also symmetric.

A short discussion at the next I.A.U. meeting would be useful.

M. MINNAERT
President of the Sub-commission

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Report of meeting. 31 August 1955

PRESIDENT: M. B. Edlén.

SECRETARY: Mme C. Moore-Sitterly.

The President discussed item by item the printed Draft Report of the Commission. With regard to the Primary Standard, he pointed out that in adhering to the present recommendation, Commission 14 will cease to be the ultimate authority if and when the primary standard of wave-length becomes identical with the primary standard of length. The question is now referred to the International Committee on Weights and Measures. Commission 14 passed a resolution recommending that the I.A.U. endorse the proposals regarding the future primary standard of wave-length, made by the Advisory Committee for Re-defining the Metre and stated in the Draft Report, p. 201 of this volume.

It was agreed that the Dispersion Formula proposed by Edlén in 1952 represents the best present knowledge of the index of refraction of air, although it is extrapolated for wave-lengths longer than 6438 Å. Essen pointed out that this formula fits present measurements in the microwave region within the errors of observation. The Commission passed a resolution that the I.A.U. recommend for the conversion of wave-lengths in standard air to wave-lengths in vacuum and vice versa, the use of the dispersion formula adopted by the Joint Commission for Spectroscopy in Rome in 1952, and given on p. 202 of this volume.

The question of accepting the combination principle as a basis for deriving secondary standards of wave-length was discussed. Meggers considered it a forward step to accept this method and noted that it would increase appreciably the available number of standards. Edlén reported on the calculations of Fe I lines, mentioned on p. 203 of this volume, and presented the final results in the form of two tables, one (Table 1) giving the energy levels and the other (Table 2) the wave-lengths calculated from these levels. The final calculation of Fe I levels is based on the measured wave-lengths of 575

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lines in the range of 9372 Å to 2501 Å, each wave-length being a weighted mean of all available determinations. Weights were assigned to the different wave-lengths according to the number and accuracy of determinations and to the wave-length region, the weights being inversely proportional to the square of the estimated wave-number uncertainty. The weights ranged from 2 to 60 on an arbitrary scale. A total of 55 even and 138 odd levels was involved. A number of additional levels were afterwards added, some of which were derived from one combination only. In the deep red and infra-red, where no observations with the standard long arc exist, only 'stable' lines had been utilized. In other parts of the spectrum some multiplets involving the high even terms e^7D, e^5D, and e^5F had been included. Wave-lengths derived from combinations with high even levels are marked 'e' in Table 2 to indicate that they are less stable than the others, and are recommendable as standards only when the standard long arc is being used. The wave-length table gives the calculated wave-lengths of 1016 lines between 2080 Å and 12,000 Å. (The level combination for each line can be found in the monograph by H. N. Russell and C. E. Moore, *Trans. Am. Phil. Soc.* **34**, part 2, 1944.)

A detailed account of the work will be published. Mimeographed copies of the tables may be obtained from the Department of Physics, University of Lund. The Commission passed a resolution recommending that the I.A.U. adopt as secondary standards of wave-length the calculated wave-lengths of 1016 lines in the spectrum of the iron arc in air, as given in the list presented at the Commission meeting, and included as Table 2 in this Report, p. 220. This list is to replace the iron standards previously adopted.

TABLE 1. Fe I *energy levels*; *arc-in-air values*

a $^5D_4$	0·000	c $^3P_2$	24 335·764	z $^7F_6$	22 650·415	y $^5F_5$	33 695·378
$^5D_3$	415·932	$^3P_1$	24 772·019	$^7F_5$	22 845·856	$^5F_4$	34 039·495
$^5D_2$	704·003	a $^1G_4$	24 574·655	$^7F_4$	22 996·661	$^5F_3$	34 328·733
$^5D_1$	888·132	b $^3H_6$	26 105·908	$^7F_3$	23 110·925	$^5F_2$	34 547·192
$^5D_0$	978·076	$^3H_5$	26 351·049	$^7F_2$	23 192·486	$^5F_1$	34 692·130
a $^5F_5$	6 928·266	$^3H_4$	26 627·612	$^7F_1$	23 244·826	z $^3P_2$	33 946·920
$^5F_4$	7 376·762	a $^3D_3$	26 224·961	$^7F_0$	23 270·374	$^3P_1$	34 362·860
$^5F_3$	7 728·058	$^3D_2$	26 623·726	z $^7P_4$	23 711·443	$^3P_0$	34 555·586
$^5F_2$	7 985·783	a $^1D_2$	28 604·610	$^7P_3$	24 180·848	z $^5G_5$	34 782·406
$^5F_1$	8 154·713	a $^1H_5$	28 819·966	$^7P_2$	24 506·902	$^5G_4$	35 257·309
a $^3F_4$	11 976·239	a $^1I_6$	29 313·008	z $^5D_4$	25 899·974	$^5G_3$	35 611·608
$^3F_3$	12 560·933	c $^3F_4$	32 873·623	$^5D_3$	26 140·164	$^5G_2$	35 856·386
$^3F_2$	12 968·552	$^3F_3$	33 412·706	$^5D_2$	26 339·682	z $^3G_5$	35 379·189
a $^5P_3$	17 550·180	$^3F_2$	33 765·291	$^5D_1$	26 479·366	$^3G_4$	35 767·546
$^5P_2$	17 726·985	e $^7D_5$	42 815·814	$^5D_0$	26 550·466	$^3G_3$	36 079·353
$^5P_1$	17 927·378	$^7D_4$	43 163·282	z $^5F_5$	26 874·534	y $^3F_4$	36 686·159
a $^3P_2$	18 378·187	$^7D_3$	43 434·585	$^5F_4$	27 166·804	$^3F_3$	37 162·729
$^3P_1$	19 552·474	$^7D_2$	43 633·491	$^5F_3$	27 394·676	$^3F_2$	37 521·144
$^3P_0$	20 037·815	$^7D_1$	43 763·938	$^5F_2$	27 559·568	y $^5P_3$	36 766·950
a $^3H_6$	19 390·165	e $^5D_4$	44 676·963	$^5F_1$	27 666·334	$^5P_2$	37 157·546
$^3H_5$	19 621·004	$^5D_3$	45 061·287	z $^5P_3$	29 056·312	$^5P_1$	37 409·530
$^3H_4$	19 788·248	$^5D_2$	45 333·834	$^5P_2$	29 469·010	y $^3D_3$	38 175·332
b $^3F_4$	20 641·110	$^5D_1$	45 509·112	$^5P_1$	29 732·721	$^3D_2$	38 678·015
$^3F_3$	20 874·482	$^5D_0$	45 595·046	z $^3F_4$	31 307·235	$^3D_1$	38 995·717
$^3F_2$	21 038·987	e $^5F_5$	47 005·455	$^3F_3$	31 805·059	x $^5D_4$	39 625·784
a $^3G_5$	21 715·735	$^5F_4$	47 377·909	$^3F_2$	32 133·977	$^5D_3$	39 969·830
$^3G_4$	21 999·132	$^5F_3$	47 755·485	z $^3D_3$	31 322·603	$^5D_2$	40 231·312
$^3G_3$	22 249·430	z $^7D_5$	19 350·882	$^3D_2$	31 686·342	$^5D_1$	40 404·492
b $^3P_2$	22 838·320	$^7D_4$	19 562·435	$^3D_1$	31 937·308	$^5D_0$	40 491·260
$^3P_1$	22 946·810	$^7D_3$	19 757·020	y $^5D_4$	33 095·922	x $^5F_5$	40 257·300
$^3P_0$	23 051·744	$^7D_2$	19 912·486	$^5D_3$	33 507·102	$^5F_4$	40 594·413
b $^3G_5$	23 783·617			$^5D_2$	33 801·555	$^5F_3$	40 842·130
$^3G_4$	24 118·815			$^5D_1$	34 017·084		

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TABLE 1. Fe I *energy levels* (*cont.*)

$^3G_3$	24 338·766	$^7D_1$	20 019·631	$^5D_0$	34 121·581	$^5F_2$	41 018·029
z $^5S_2$	40 894·972	y $^3G_5$	45 294·830	w $^5G_5$	47 420·215	z $^1D_2$	49 477·111
x $^5P_3$	42 532·729	$^3G_4$	45 428·385	$^5G_2$	47 831·132	w $^3P_2$	50 186·814
$^5P_2$	42 859·756	$^3G_3$	45 562·959	z $^1G_4$	47 452·702	z $^1F_3$	50 586·857
$^5P_1$	43 079·013	x $^5G_6$	45 608·341	y $^3S_1$	47 555·584	x $^1G_4$	50 613·965
y $^5G_5$	42 911·897	$^5G_5$	45 726·104	v $^5F_5$	47 606·092	u $^3G_5$	51 373·894
$^5G_4$	43 022·969	$^5G_3$	45 913·480	$^5F_4$	47 929·981	$^3G_4$	51 668·175
$^5G_3$	43 137·472	$^5G_2$	45 964·944	$^5F_3$	48 122·913	$^3G_3$	51 825·758
$^5G_2$	43 210·011	w $^5P_1$	46 410·366	$^5F_2$	48 238·832	t $^3D_3$	52 213·207
z $^5H_5$	42 991·680	z $^3S_1$	46 600·800	x $^3G_5$	47 834·529	w $^3H_5$	52 613·072
$^5H_4$	43 108·899	y $^3P_2$	46 727·055	$^3G_4$	47 812·104	y $^3I_7$	52 654·971
$^5H_3$	43 325·946	$^3P_1$	46 901·808	v $^5P_3$	47 966·571	$^3I_6$	52 513·546
w $^5D_4$	43 499·485	$^3P_0$	46 672·523	$^5P_2$	48 163·427	$^3I_5$	52 898·980
$^5D_3$	43 922·652	u $^5D_4$	46 720·824	$^5P_1$	48 289·852	v $^3P_2$	52 916·278
$^5D_2$	44 183·607	$^5D_3$	46 744·975	x $^3P_2$	48 304·623	z $^1I_6$	53 093·517
$^5D_1$	44 411·137	$^5D_2$	46 888·494	z $^1H_5$	48 382·585	t $^5P_2$	54 112·203
w $^5F_5$	44 243·668	$^5D_1$	47 177·210	y $^1G_4$	48 702·518	v $^3H_6$	55 489·733
$^5F_4$	44 022·518	x $^3F_4$	46 889·126	w $^3F_4$	49 108·876	$^3H_5$	55 429·799
$^5F_2$	44 285·436	$^3F_3$	47 092·693	$^3F_3$	49 242·872	u $^3H_5$	56 382·664
v $^5D_4$	44 415·057	$^3F_2$	47 197·000	$^3F_2$	49 433·108	$^3H_4$	56 423·276
$^5D_3$	44 551·325	z $^3H_6$	46 982·302	v $^3D_3$	49 135·003	u $^3F_3$	56 783·306
$^5D_2$	44 664·061	$^3H_5$	47 008·351	y $^3H_6$	49 434·142	x $^3I_6$	57 070·171
$^5D_1$	44 760·739	$^3H_4$	47 106·463	$^3H_5$	49 604·402	$^3I_5$	57 104·207
y $^5S_2$	44 511·795	w $^3D_3$	47 017·170	$^3H_4$	49 726·964		
x $^3D_3$	45 220·662	$^3D_2$	47 136·058	v $^3G_5$	49 460·876		
$^3D_2$	45 281·816	$^3D_1$	47 271·999	$^3G_4$	49 627·861		
$^3D_1$	45 551·748						

TABLE 2. *Wave-lengths in the iron arc in air*

11973·067	8838·434	7443·019	6574·231
11884·097	8824·227	7418·673	6546·245
11882·861	8804·637	7401·690	6518·374
11783·275	8757·192	7284·842	6498·943
11689·988	8688·632	7223·668	6494·985
11638·279	8674·753	7219·686	6481·877
11607·587	8661·907	7207·116	6475·632
11593·600	8621·613	7132·990	6462·730
11439·129	8611·807	7112·177	6430·852
11422·335	8582·268	7107·462	6421·355
11374·095	8515·122	7068·413	6411·659 e
11119·809	8514·079	7024·068	6408·028 e
10395·811	8468·414	7016·062	6400·321
10340·898	8387·780	6988·531	6400·013 e
9372·904	8365·642	6978·856	6393·605
9362·371	8327·063	6945·208	6380·746
9359·419	8293·523	6839·837	6358·696
9210·033	8239·130	6806·851	6355·035
9146·138	8096·881	6750·155	6344·154
9118·892	8075·156	6703·574	6336·833 e
9089·415	8047·621	6677·994	6335·337
9088·324	7912·867	6663·444	6322·691
8999·564	7748·278	6609·117	6318·023
8975·410	7723·213	6593·875	6301·510 e
8943·078	7664·301	6592·920	6297·798
8868·442	7583·797	6575·024	6280·621

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6265·140	5269·5402	4910·0253 e	4442·3428
6256·367	5266·5626 e	4903·3169 e	4439·8849
6254·263	5263·3134 e	4891·4989 e	4436·9246
6252·561	5250·6490	4890·7616 e	4435·1500
6246·329 e	5242·4955	4878·2182 e	4432·5729
6240·649	5232·9474 e	4872·1444 e	4430·6175
6232·650 e	5227·1911	4871·3244 e	4427·3118
6230·728	5226·8686 e	4859·7480 e	4422·5703
6219·286	5217·3964 e	4855·6812 e	4415·1250
6213·435	5216·2770	4844·0158	4408·4176
6200·319	5215·1871 e	4839·5510	4407·7130
6191·563	5208·6007 e	4789·6537	4404·7525
6173·341	5204·5840	4788·7606	4401·4456
6165·364	5202·3395	4786·8106	4390·9542
6157·732	5198·7149	4771·7008	4389·2467
6151·623	5194·9441	4741·5321	4387·8959
6141·741 e	5192·3509 e	4740·3434	4383·5473
6137·697	5191·4615 e	4736·7807 e	4375·9318
6137·000	5171·5987	4733·5955	4369·7745
6136·621	5168·9003	4710·2864	4367·9059
6065·488	5167·4905	4707·4908	4367·5811
6027·057	5166·2841	4707·2807 e	4358·5037
5956·697	5151·9143	4691·4144	4352·7371
5916·252	5150·8425	4683·5640	4351·5465
5709·3864 e	5142·9320	4680·2983	4348·9398
5701·5511	5141·7424	4668·1422 e	4346·5571
5658·8247 e	5139·4702 e	4661·9726	4337·0484
5624·5501 e	5139·2578 e	4654·5020	4326·7555
5615·6521 e	5131·4734	4647·4370	4325·7647
5615·3039	5127·3624	4632·9149	4315·0872
5602·9529 e	5123·7231	4630·1248	4309·3771
5586·7634 e	5110·4139	4625·0527 e	4307·9048
5572·8501 e	5107·6439	4618·7604	4305·4545
5569·6256 e	5107·4505	4602·9446	4304·5436
5506·7824	5098·7030	4602·0040	4302·1882
5501·4686	5083·3413	4595·3627	4299·2409 e
5497·5196	5079·7426	4592·6547	4298·0403
5455·6131	5079·2279	4574·7225	4294·1271
5446·9197	5068·7730 e	4547·8505	4288·1484
5434·5268	5051·6379	4547·0206	4285·4453
5429·6999	5049·8253	4531·1520	4282·4057
5405·7781	5041·7585	4528·6175	4271·7634
5397·1311	5041·0747	4517·5289	4271·1589 e
5393·1752 e	5028·1331	4514·1876	4266·9675
5371·4926	5012·0712	4494·5669	4260·4794 e
5365·4062	5006·1254 e	4490·0872	4258·3174
5341·0255	5002·7998 e	4489·7416	4250·7896
5339·9371 e	4994·1323	4482·2563	4250·1248 e
5332·9020	4985·5539 e	4482·1720	4248·2275
5328·5336	4966·0968 e	4480·1397	4245·2594
5328·0418	4957·6059 e	4476·0206	4235·9433 e
5324·1864 e	4957·3054 e	4466·5542	4233·6089 e
5322·0456	4950·1144 e	4464·7691	4229·7561
5307·3633	4946·3944 e	4461·6544	4226·4263
5302·3073 e	4939·6896	4459·1213	4222·2181 e
5283·6283 e	4938·8206 e	4456·3294	4219·3641
5281·7970 e	4924·7753	4454·3835	4216·1854
5273·1708 e	4920·5096 e	4447·7212	4210·3497 e
5270·3602	4919·0003 e	4443·1963	4207·1298

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TABLE 2. *Wave-lengths in the iron arc in air* (*cont.*)

4206·6985	4001·6627	3867·2184	3745·5623
4203·9867	4000·4598	3865·5256	3743·3640
4202·0320	3998·0554	3859·9132	3738·3078
4199·0981	3997·3952	3859·2143	3737·1333
4198·3098 e	3995·9861	3856·3731	3734·8659
4195·6205	3994·1166	3852·5752	3733·3191
4191·4358 e	3990·3766	3850·8193	3731·3761
4187·8015 e	3983·9593	3849·9694	3730·3884
4187·0436 e	3981·7743	3846·8023	3728·6696
4184·8941	3977·7437	3845·1706	3727·6211
4182·3846	3971·3250	3843·2596	3724·3796
4181·7571	3969·2595	3841·0499	3722·5642
4177·5949	3967·4234	3840·4397	3722·0263
4175·6386	3966·0645	3839·2584	3719·9367
4174·9137	3964·5173	3837·1370	3718·4092
4173·9230	3956·6796	3834·2244	3715·9136
4173·3178	3956·4574	3833·3103	3711·2243
4172·7454	3953·1548	3830·8638	3709·2484
4170·9044	3952·6045	3830·7607	3707·9216
4156·8021	3949·9558	3829·7637	3707·8231
4154·5021	3948·7778	3827·8256	3705·5674
4152·1704	3944·8924	3827·5746	3704·4635
4147·6719	3943·3414	3825·8834	3687·4589
4143·8703	3942·4418	3824·4455	3687·0982
4143·4174	3940·8797	3824·0763	3684·1102
4139·9288	3937·3310	3821·8357	3683·0562
4134·6798	3935·8143	3821·1807	3679·9152
4132·9024	3930·2981	3820·4274	3678·8620
4132·0603	3927·9216	3816·3421	3677·6309
4127·6113	3925·6460	3815·8430	3676·3135
4125·8831	3922·9134	3814·5247	3669·5229
4121·8050	3920·2601	3812·9658	3659·5188
4120·2087	3919·0681	3808·7306	3655·4671
4118·5484	3918·3174	3807·5392	3651·4699
4114·4485	3917·1834	3806·6992	3650·2811
4109·8053	3913·6339	3805·3450	3649·5090
4107·4917	3910·8461	3801·6817	3649·3045
4100·7389	3907·9371	3799·5498	3647·8439
4095·9731	3906·4814	3798·5134	3640·3918
4091·5566	3903·9011	3797·9502	3638·2998
4079·8411	3902·9484	3795·0045	3632·9799
4078·3563	3899·7086	3790·0943	3631·4646
4074·7889	3898·0111	3789·1783	3623·1878
4071·7399	3897·4515	3787·8825	3621·4640
4067·2738	3895·6579	3786·6781	3618·7694
4063·5963	3893·9141	3778·6986	3608·8609
4062·4440	3893·3935	3777·4521	3606·6821
4058·7562	3888·5165	3776·4553	3603·2068
4057·3456	3887·0504	3774·8266	3589·1063
4055·0376	3886·2839	3767·1939	3586·9861
4045·8147	3885·5121	3765·5414	3585·7068
4044·6125	3884·3609	3763·7910	3585·3206
4032·6294	3878·5745	3761·4103	3584·6627
4030·1855	3878·0206	3760·5335	3581·6499
4021·8696	3876·0414	3758·2350	3571·2265
4017·1524	3873·7624	3753·6134	3570·0996
4009·7154	3872·5032	3749·4875	3568·9778
4007·2735	3871·7513	3748·2639	3565·3807
4005·2440	3869·5615	3745·9013	3558·5170

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TABLE 2. *Wave-lengths in the iron arc in air* (*cont.*)

3554·1196	3355·2287	3091·5786	2936·9049
3540·7111	3351·7457	3083·7430	2929·6195
3526·4695	3351·5239	3075·7214	2929·0085
3526·1676	3347·9271	3068·1749	2925·9012
3526·0415	3342·2163	3067·2457	2920·6915
3524·2417	3340·5666	3067·1196	2914·3055
3521·2630	3337·6664	3060·9849	2912·2582
3513·8196	3335·7699	3059·0871	2912·1589
3506·5004	3334·2201	3057·4471	2901·3820
3504·8636	3331·6133	3055·2638	2895·0362
3500·5675	3328·8667	3047·6060	2894·5055
3497·8420	3327·4970	3042·6667	2893·8822
3495·2879	3324·5385	3042·0215	2886·3174
3490·5749	3323·7375	3041·7401	2880·5806
3485·3418	3314·7420	3041·6386	2877·3021
3483·0090	3305·9719	3040·4281	2875·3034
3476·7036	3298·1331	3037·7809	2874·1733
3475·4511	3292·5910	3037·3901	2872·3346
3471·3460	3290·9899	3030·1494	2869·3083
3471·2672	3286·7541	3029·2351	2867·5632
3468·8474	3284·5888	3026·4637	2866·6264
3466·5001	3280·2613	3025·8442	2863·8644
3465·8621	3276·4713	3024·0337	2863·4311
3463·3044	3271·6842	3021·0743	2862·4952
3462·3539	3271·0014	3020·6405	2858·8970
3452·2760	3265·6182	3020·4918	2853·6855
3451·9166	3265·0473	3018·9848	2851·7979
3450·3304	3263·3697	3017·6288	2848·7153
3447·2797	3257·5940	3014·1747	2846·8312
3445·1508	3254·3628	3009·5707	2845·5959
3443·8775	3252·9160	3009·0945	2843·9775
3442·6709	3250·6250	3008·1399	2843·6314
3440·9899	3246·4816	3007·2832	2840·9382
3440·6069	3246·0054	3007·1469	2840·4229
3428·1948	3236·2231	3003·0323	2838·1205
3427·1213	3234·6138	3000·9489	2835·9511
3424·2861	3229·1221	3000·4527	2835·4574
3422·6583	3226·7137	2999·5125	2832·4364
3417·8428	3214·3964	2996·3864	2828·8094
3415·5318	3200·7854	2994·5033	2827·8931
3413·1339	3193·2268	2994·4281	2825·6888
3407·4611	3191·6599	2990·3933	2825·5569
3406·8021	3184·8955	2988·4730	2823·2767
3404·3557	3182·9798	2987·2923	2820·8039
3401·5200	3180·7562	2986·4569	2817·5047
3399·3356	3161·3728	2983·5714	2813·2877
3397·6403	3148·4078	2981·4459	2808·3281
3396·9774	3143·2434	2973·2368	2807·2461
3394·5854	3142·8908	2973·1336	2806·9852
3392·6540	3134·1115	2969·4759	2804·5212
3392·3058	3129·3349	2969·3606	2803·1675
3383·9808	3120·4364	2966·8997	2797·7765
3382·4042	3119·4956	2965·2561	2796·8721
3380·1117	3116·6337	2959·9929	2795·5409
3379·0206	3100·6667	2957·3660	2795·0065
3372·0744	3100·3054	2954·6543	2794·7033
3370·7852	3099·9695	2953·9411	2791·7867
3359·4876	3099·8968	2947·8773	2787·9331
3356·4030	3093·8063	2941·3438	2781·8368

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TABLE 2. *Wave-lengths in the iron arc in air* (*cont.*)

2778·2214	2673·2142	2496·5343	2259·5109
2772·1107	2667·9138	2494·2525	2251·8749
2772·0748	2666·9665	2491·1562	2250·7911
2769·6717	2666·8133	2490·6454	2245·6536
2769·2985	2666·3998	2488·1437	2242·5725
2767·5232	2662·0574	2487·3705	2231·2138
2766·9104	2656·7933	2483·2718	2229·0735
2762·7732	2651·7075	2479·7774	2228·1722
2762·0275	2647·5588	2479·4813	2211·2364
2761·7810	2645·4230	2474·8151	2210·6894
2757·3170	2643·9992	2472·8962	2207·0692
2756·3295	2641·6468	2468·8803	2196·0427
2756·2677	2636·4794	2467·7330	2191·2052
2754·4273	2635·8100	2465·1500	2187·1950
2754·0332	2632·5951	2462·6483	2186·8933
2750·1415	2632·2382	2462·1822	2180·8692
2747·5564	2623·3669	2457·5980	2176·8414
2744·5287	2618·7111	2453·4767	2173·2146
2744·0691	2618·0191	2447·7108	2172·5858
2742·4064	2614·4952	2445·2134	2171·2976
2742·2554	2612·7734	2443·8728	2164·5495
2742·0164	2606·8280	2438·1831	2163·8633
2741·5781	2605·6578	2389·9732	2161·5802
2738·2143	2584·5370	2381·8356	2159·6583
2737·3108	2580·4542	2374·5192	2158·9207
2735·4762	2580·0662	2373·6250	2157·7951
2734·6165	2576·6916	2371·4313	2155·0203
2734·2691	2564·5609	2369·4567	2153·0075
2734·0060	2561·8562	2329·6413	2150·1850
2733·5816	2560·5576	2320·3585	2145·1901
2730·9822	2556·3043	2313·1048	2141·7188
2728·9703	2552·8318	2308·9999	2141·0872
2728·0212	2549·6142	2303·5815	2139·6987
2725·6021	2545·9795	2301·6849	2138·5932
2724·9542	2540·9734	2299·2209	2132·0177
2723·5786	2539·3576	2298·1699	2126·2108
2720·9035	2537·4598	2297·7877	2115·1697
2718·4365	2535·6086	2296·9279	2114·6003
2717·7874	2532·8764	2293·8482	2112·9696
2714·8697	2529·8370	2292·5249	2108·9598
2711·6560	2529·1361	2291·6274	2108·3027
2706·5829	2527·4358	2287·2505	2108·1371
2699·1075	2524·2939	2284·0864	2106·3953
2697·0224	2522·8505	2283·6557	2103·0534
2695·0357	2521·9197	2283·3045	2102·3542
2692·2496	2519·6305	2276·0263	2100·7984
2690·0694	2518·1029	2272·0703	2100·1464
2689·8305	2516·5716	2270·8628	2093·6853
2689·2130	2510·8362	2269·0990	2090·3837
2680·4540	2501·6946	2267·0853	2087·5115
2679·0626	2501·1332	2265·0546	2084·1218

A similar resolution was passed recommending that the I.A.U. adopt as secondary standards of wave-length the calculated wave-lengths of 30 neon lines as given in column 2 of Table 1, on p. 205 of this volume, to replace the neon standards previously adopted.

The Commission passed a resolution recommending, also, that the I.A.U. adopt as secondary standards of wave-length the calculated wave-lengths of argon as given in

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column 2 of Tables 5 and 6, pp. 208 and 209 of this volume, with the exception of the wave-lengths in Table 5 marked 'a'.

Swings reported that Migeotte had completed the preparation of 'An Atlas of the Infra-red Solar Spectrum' covering the interval 2·8μ to 23·75 μ. The wave-lengths have been measured, and most of the identifications completed. A copy of this Atlas was exhibited during the meeting.

Swings stated, also, that Prof. J. Genard of the Physical Institute of the University of Saarbrücken planned to carry out a programme on the measurement of all band spectra of astrophysical interest. To date, four sequences of the violet CN system, between 3500 Å and 4700 Å, have been measured by Dr J. Weinard with an accuracy better than ±0·01 Å, and the results will be published in *Ann. d'Astroph.* (1956). Part of the CN spectrograms were furnished by C. C. Kiess at the National Bureau of Standards; others were obtained by J. Genard and J. Weinard at the University of Saarbrücken. The study of the bands is in progress, and revised solar identifications have been made (to be published in *Ann. d'Astroph.*). Work will be continued on the red system of CN and on other cosmically abundant molecules.

As stated in the agenda of the General Assembly, resolution 14, item (*a*), p. 26, the Commission recommended the adoption of the symbol Å for the wave-length unit, to conform to the following motion which was adopted by the Joint Commission for Spectroscopy at the Lund meeting in 1954:

Since the I.U.P.A.P., the I.A.P.A.C. and the Bureau International des Poids et Mesures have adopted Å as the symbol for the angstrom-unit and because this symbol has the great advantage over A of being absolutely unique and characteristic, the J.C.S. recommends the universal use of the symbol Å for the angstrom-unit in all spectroscopic publications.

The Draft Report as a whole was approved.

In a letter to the President, O. C. Mohler had stated that the question of excitation potentials had come up in connexion with the Michigan table of infra-red solar wave-lengths. He writes 'It seems to us that it is no longer wise to publish excitation potentials in wave-length tables if these potentials have been derived from the spectroscopic term values. A much better procedure would be to publish the term values themselves.' Mrs Sitterly commented that opinions on this question are far from unanimous. She had sent a questionnaire to about ninety workers in various fields and received forty-eight replies. The majority favoured the retention of excitation potentials in volts, calculated with the conversion factor from cm.$^{-1}$ to volts, 0·00012395, adopted by the J.C.S. in 1952.

The Commission felt that it should assume responsibility with regard to wave-length standards in the region 1 to 3 μ, and in the vacuum ultra-violet region. Edlén noted that the standards in the vacuum ultra-violet must be established by calculations based upon the combination principle. The Commission favoured extending the use of interferometric methods, including the use of the reflexion echelon, for measurements in both regions.

Meggers reported on the advantages of electrodeless high-frequency discharge lamps as sources for future spectroscopic wave-length standards, as follows:

For nearly half a century the iron arc at atmospheric pressure has been the major source of secondary standards. But this source emits lines greatly widened by Doppler effect (because the temperature is near 5000° K.), and further broadened by collision and resonance-effects, or displaced (because of atmospheric pressure). Since these lines are relatively wide, their wave-lengths cannot be individually determined with high accuracy. The iron standards now computed with higher accuracy from mean values of atomic energy levels derived from interferometer measurements mark the culmination of work of this kind, but they do not increase the accuracy of measurement of individual lines. The only way to improve the secondary iron standards is to sharpen the lines by reducing the temperature and pressure of the source. Suggestions that this be done by operating the arc at reduced pressure or by substituting

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the hollow-cathode discharge have not been generally accepted. Recently, the development of electrodeless metal vapour lamps excited by microwaves (generated by magnetrons) has made available ideally simple sources of superior secondary standards. Since these sources operate at moderate temperatures, and very low pressures, the radiations are emitted with high intensity, but with greatly reduced Doppler width and relative freedom from pressure effects or self-reversal. Such quartz lamps containing a trace of iron halide, and 1–2 mm. of argon gas, emit iron lines that produce interference patterns with four to five times the interference order obtainable with the standard arc.

The iron spectrum as a source of secondary standards has been criticized by spectroscopists working with very high dispersion because it does not permit the determination of standards throughout the spectrum at intervals of a few angstroms. Simple electrodeless ultra-high-frequency lamps containing thorium or uranium halides are suggested as sources of future secondary standards that will satisfy all foreseeable needs for making accurate descriptions of extremely complex spectra like those characterizing the rare-earth elements. Both 90Th and 92U occur naturally as practically pure even-mass isotopes (232 and 238, respectively) and, therefore, emit lines of minimum Doppler width completely free of isotopic structure (and pressure shifts).

Jackson reported that he had developed and used since 1928 a similar method of producing spectra with narrow lines from metals or metallic halides, by means of a high-frequency discharge in a carrier gas. The chief differences from Meggers' method were that (1) the wave-length of the oscillator used for producing the discharge was much longer, approximately 30 m.; and (2) the design of the discharge tubes was such that the vapour pressure of the metal or metallic halide could be controlled to any desired value, and was not determined by the heating effect of the discharge. The discharge tube must have fairly large end-pieces, with external electrodes in the form of thin copper foil wrapped around them. With the carrier gases helium or neon he has succeeded in observing the resonance lines of Cs, Rb, and K free from self-reversal. Similarly, by using thallous chloride, indium trichloride, and gallium tribromide, with the vapour pressure of the halides so high that the helium spectrum is almost extinguished, the resonance lines of the metals are quite free from the effects of self-reversal or self-absorption. With silver chloride precise control of temperature and vapour is necessary, as with the alkali metals, to avoid self-reversal. Jackson described, also, a very simple design for a cooled hollow cathode tube that could be constructed at little expense and quickly assembled.

The Commission recommended the investigation of the hollow cathode tube and the electrodeless discharge as sources for future work on secondary standards.

Engelhard discussed the merits of a primary standard of krypton. He described the Kr^{84} lamp developed by himself as an ideal source for the primary standard of wave-length.

Barrell felt that at present Kr^{84} was the best source, although Hg^{198} in a hollow cathode or an atomic beam may ultimately prove to be superior. He strongly recommended the adoption of a fixed path difference of 125 mm., i.e. an etalon length of 62·5 mm., in interferometric comparisons with the present primary standard. The adoption of one specific path difference simplifies procedure and eliminates from the results any small variations due to the effects of possible hyperfine structure in the cadmium red line.

Barrell submitted the following provisional interferometric vacuum wave-length measurements of Hg^{198} lines excited in water-cooled lamps at 20°C.:

5792·2680	5462·2702	4359·5620	4078·9889
5771·1979		4348·7175	4047·7141

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Report of the meeting of Sub-commission 14a. 31 August 1955

PRESIDENT: Prof. M. Minnaert.

SECRETARY: Prof. C. W. Allen.

The Draft Report of the sub-commission was approved.

The commission discussed a proposal by D. H. Menzel and D. Layzer that the single quantity line-strength S be used for expressing intensities of spectrum lines. In the discussion that ensued, the advantages and disadvantages of using the quantity S were tabulated as follows:

Advantages. S is symmetric with respect to the initial and final level (although this applies also to gf). S can be readily extrapolated along iso-electronic sequences. Multiplet sum-rules are more fundamental than f sum-rules. Formulae relating to line and multiplet strengths may be simply derived from the strength of the whole multiplet.

Disadvantages. The S unit is different for dipole, quadrupole and magnetic dipole radiations. There are some general quantum mechanical calculations, for example those depending on electron acceleration rather than electric moment, that are not related directly to S.

The alternatives suggested for S were gf, $gf\lambda$, and $gf\lambda/\lambda_0$, where g is statistical weight, f oscillator strength, λ wave-length and λ_0 a standard wave-length. It was decided that f should not be used alone for this purpose (as it is unsymmetrical), but that the relative advantages of using S, gf, $gf\lambda$, and $gf\lambda/\lambda_0$ should be determined by usage during the next three years.

There was a discussion on the question of producing a general table of transition probabilities by the sub-commission. It was agreed that such a table would be of great use, but difficult problems of the contents and form suitable for such tables are involved.

C. W. Allen gave a brief account of the differences between calculated and observed oscillator strengths for lines of the Fe group of atoms. The discrepancies are very closely related to the excitation potential.

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