CHAPTER V

RESULTS AND DISCUSSION

RESULTS

5.1 RESULTS

In this section the results of measurements at room temperature on the excitation and emission spectra of NaBr:Tl phosphors containing varying amounts of thallium, in as-received condition and after various pretreatments are reported. The preperation of the specimens involved crystallization of sodium bromide, with different quantities of thallous bromide, from aqueous solutions. Like other alkali halides, sodium bromide does not luminesce strongly in the pure state, though a weak luminescence has been reported earlier in alkali halides at 300°K[4] . Necessary precautions were therefore taken against the misinterpretation of the experimental data that may be attributed to intrinsic luminescence. The excitation and emission spectra presented in the thesis have been therefore corrected, wherever necessary, by subtracting very low intensity excitation and emission of as-received and thermally treated (in vacuum) pure NaBr specimens from those of the corresponding thallium doped specimens. It may be mentioned that the

luminescence of pure NaBr specimen heated in open air is quite marked. Luminescence of this nature is not included in the study of Tl doped NaBr . Heat treatment to Tl doped specimens was imparted in vacuum. Precautions were also taken to remove the effect of scatter in the instrument by using suitable filters. Luminescence measurements were carried out for a number of specimens and the typical luminescence spectra are presented for discussion. In all the cases the excitation spectrum of a given specimen was first observed and subsequently its emission spectrum stimulated by the observed excitation was recorded. Each excitation and emission band is designated by the wavelength at which its peak appears. It should be mentioned that a band may not appear isolated and may possess satellites to the higher or lower wavelength side. In such a case, changes in the relative intensities of the components within a composite band would lead to an apparent shift in the position of its maximum. In this respect the peak positions indicated can only be regarded as approximate. Wherever necessary, the complex excitation and emission bands have been analysed

by the superposition of bell-shaped curves. The intensities of the excitation and emission bands are given in absolute units. The results for the luminescence spectra of undoped sodium bromide are presented first. Overall examination of the excitation and emission spectra of Tl doped sodium bromide obtained in the present measurements indicates that the emission bands can be classified into three groups on the basis of the region in which they appear. The three groups are : emission bands in the i) ultraviolet region, ii) near ultraviolet region, and iii) visible region.

I UNDOPED NaBr :

(Figs. 1 and 2) :

The excitation and emission data presented in Figs. 1 and 2 relate to the undoped NaBr powder specimens annealed at 500°C and subsequently quenched to room temperature and also include the data for the same specimens after compression to tablets. From these Figs. It is obvious that the excitation spectra

for the specimens consist of a single dominant band around 270 nm and the emission spectrum induced by this excitation display a prominent band at 360 nm. Since the undoped NaBr powder as-received from the manufacturers involved some unavoidably present impurities, it was believed that such impurities might have a role in the occurrence of 270 nm excitation and 360 nm emission. However, measurements carried out for the luminescence spectra of the specimens indicate that there is a marked increase in the intensity of the excitation band at 270 nm or the emission band at 360 nm if the heat treatment is given in open air instead of in evacuated and sealed tube (Fig.2a, Compare : Curves 1 and 2). In the same manner, the inhancement in the intensity of the excitation or emission band is observed if the specimen is annealed at higher temperature instead of at lower temperature, other conditions remaining the same (Fig. 2a, Compare : Curves 2 and 3). A weak subsidiary band at 432 nm is observed in the emission spectra of the above specimens after compression to tablet.(Fig. 2b).

II DOPED NaBr :

i) ULTRAVIOLET EMISSION :

Figs. 3 through 16 represent the luminescence data for the ultraviolet emission of the phosphors obtained by crystallization from solution with Tl concentration varying in the range between 10^{-4} to 10^{-1} molar fraction. The data also include the excitation and emission spectra for pretreated specimens.

(Figs. : 3 - 6) :

Fig. 3, Curves : 1 and 2 represents the excitation spectra for 328 nm emission of the phosphors with 10^{-4} and 10^{-3} m.f. Tl . These spectra consist of a prominent excitation band at 268 nm and a weaker excitation band at 228 nm . Fig. 4, Curves : 1 and 2 shows that the excitation of these phosphors at 268 nm gives the principal emission at 328 nm .. Fig. 5, Curves : 1 and 2 indicates the excitation spectra of the phosphors with 10^{-2} and 10^{-1} m.f. Tl . In these cases besides 328 nm emission, other emission bands in the near ultraviolet and visible region also appear

(Fig. 6). It is clearly seen from the figures that the increase of Tl concentration brings about decrease in the strength of 268 nm excitation and the corresponding 328 nm emission.

(Figs. : 7 and 8) :

Fig. 7, Curves : 1 and 2 exhibits the excitation spectra for 328 nm emission of two as-received powder specimens (Tl conc : $\sim 10^{-4}$ and 10^{-3} m.f.) compressed to tablet. In both the cases the excitation spectrum displays bands at 228 nm and 268 nm . Fig. 8, Curves : 1 and 2 shows that the excitation of the phosphor at 268 nm gives rise to emission at 328 nm alongwith other emission bands on the higher wavelength side.

(Figs. : 9 - 12) :

The excitation and emission spectra of the phosphors annealed at 500°C in evacuated and sealed tubes and subsequently quenched to room temperature, in as-received condition and after compression to tablet, are presented in Figs. 9 to 12 . As-received phosphors

(Tl conc : 10^{-4} and 10^{-3} m.f.) exhibit prominent excitation band at 268 nm and a weaker one at 228 nm (Fig. 9, Curves : 1 and 2) for 328 nm emission. The emission spectra excited by the band at 268 nm consist of the emission band at 328 nm and the other band at 350 nm (Fig. 10, Curves : 1 and 2).

Compression of the thermally pretreated (in vacuum) powder specimen to tablet, leads to a decrease in the intensities of the excitation (at 268 and 228 nm) and emission (at 328 nm) bands (Figs. 11 and 12).

(Figs. : 13 - 16) :

Fig. 13, Curves 1 and 2 illustrate the excitation spectra of the specimens annealed at 500°C in evacuated and sealed tubes and then slowly cooled to room temperature with 10^{-4} and 10^{-3} m.f. Tl , measured for emission at 328 nm . Fig. 15 exhibits excitation spectra for the above specimens (for 328 nm emission) after compression to tablets. In all the cases the excitation spectrum displays a prominent band at 268 nm and a weaker one at 228 nm . The emission spectra for

the above specimens, when excited by irradiation into 268 nm band, exhibit 328 nm band and other bands on the long wavelength side (Figs. : 14 and 16). In this case also it is observed that deformation supresses the 328 nm emission.

ii) NEAR ULTRAVIOLET EMISSION :

Figs. 17 through 32 represent the luminescence data for near ultraviolet emission of the phosphors. This emission has observed to be significant when the Tl concentration is high, (i. e $>10^{-3}$ m.f.). These specimens prepared by crystallization from aqueous solution, were examined in as-received condition and after subjecting them to various pretreatments.

(Figs. :17 - 20) :

The excitation spectra of as-received specimens with Tl concentration 10^{-2} and 10^{-1} m.f. , are presented in Figs. 17 and 19 . The excitation spectra for these specimens in general, exhibit a principal band around 270 nm and a subsidiary band around 240 nm . The emission spectra excited by these

bands are shown in Figs. 18 and 20 . Excitation of the phosphor by absorption of light at 240 nm gives rise to emission spectrum more or less similar to the one excited by 270 nm band. The difference in the intensities of the bands in the emission spectra excited by 240 and 270 nm band is clearly observable.

(Figs. : 21 - 24) :

The excitation and emission spectra of the as-received specimens compressed to tablets are presented in Figs. 21 - 24 . It is noted that in the above specimens there is an overall decrease in the intensity of the near ultraviolet emission and simultaneously one observes an increase in the intensities of the bands in the visible region (Compare : Curves 1 and 2 of Figs. 18 and 20 with the corresponding Curves of Figs. 22 and 24 respectively).

(Figs.:25 - 28) :

Figs 25 - 28 represent the excitation and the emission spectra of the specimens, annealed at 500°C in evacuated and sealed tubes and the quenched to room

temperature, in as-received condition and after compression to tablet. The excitation spectra of these specimens also exhibit two bands, one around 242 nm and the other around 272 nm . Excitation of the specimens either at 242 nm or at 272 nm gives rise to emission in the near ultraviolet region as a shoulder on the emission band in the visible region at 420 nm .. The data presented in the Figs. correspond to emission induced only by principal excitation around 272 nm .. Subsidiary emission bands at 450, 480 and/or 500 nm are also discernible. It is observed that compression of the above specimens subsides the near ultraviolet emission.

(Figs. : 29 - 32) :

The excitation and emission spectra of the specimens annealed at 500°C (in vacuum) and then cooled slowly, in as-received condition and after deformation by stressing were also recorded. Figs. 29 and 31 respectively demonstrate the excitation data for the specimens before and after compression to tablet. It is seen that in all the cases the excitation spectrum

consists of a dominant band around 274 nm and a subsidiary band around 242 nm. Further it is observed that in the emission spectra of the above specimens before compression, the near ultraviolet emission is significant when Tl concentration is $\sim 10^{-2}$ m.f. . When the concentration is increased to 10^{-1} m.f. , the near ultraviolet emission is overshadowed by the emission in the visible at 420 nm . Compression of the annealed and slowly cooled specimen leads to appearance of additional bands (450 and 480 nm) in the visible region.

iii) VISIBLE EMISSION :

It has been mentioned before that the near ultraviolet emission of the phosphor is conspicuously observed in the untreated and pretreated specimens when Tl concentration exceeds 10^{-3} m.f. . In addition to this, visible emission for the NaBr:Tl phosphor is also favoured when Tl concentration is higher. However, one significant difference between the phosphors favouring near ultraviolet and visible emission is that the thermal and/or mechanical treatment

selectively enhances emission in the visible. The data obtained for visible emission is presented in the Figs. 17 through 32 alongwith the near ultraviolet emission. The visible emission bands observed are around 420, 450, 480 and 500 nm . The band about 420 nm is preferably observed as a dominant band when a high Tl content specimen is subjected to prolonged anneal at 500°C (in vacuum) and then quenched, and also when the specimen is annealed (in vacuum) and then cooled slowly. The emission in the other two bands, around 450 and 480 nm, is selectively observed when heavily doped specimen is deformed by stressing. The band around 500 nm is mainly favoured if the specimen with higher Tl concentration ($\sim 10^{-1}$ m.f.) is annealed at elevated temperature (in vacuum) and subsequently cooled slowly.

The visible emission around the bands mentioned above is favoured by excitation of the specimen into wavelengths ranging between 244 to 250 nm and 274 to 280 nm . These excitation regions have extensive overlap with the similar excitation regions responsible for near ultraviolet emission. However, on detailed examination it is noticed that the excitation band maxima in the two

ranges for visible emission appear on the longer wavelength side. On an average, one may attribute near ultraviolet emission to excitation at 242 and 273 nm whereas the visible emission can be associated with excitation at 247 and 277 nm . The illustrative excitation spectra for visible emission in the case of untreated and pretreated specimens with highest Tl concentration ($\sim 10^{-1}$ m.f.) are presented in Figs. 33 through 35 .

Results described above for NaBr:Tl phosphors, as-received from solution, with four different Tl concentrations are summarized in Table 1. The table also incorporates the data obtained for variously pretreated NaBr:Tl phosphors. In this tablet and the others following, the number in the bracket refers to Fig. number and the abbreviations given above the emission wavelengths indicate the relative strength of the emission bands. The following abbreviations are used :

S-strong ; M-medium ; W-weak ;.

TABLE : 11 :

Excitation and Emission Bands Displayed by Untreated and Pretreated NaBr:Tl Phosphors Differing in Tl Conc.

(Wavelength in nm)

Sr. No.	Specimen	Tl Conc. in m.f.	Excitation Band (Principal)	Emission	
				Band/ Bands favoured	Other bands
1.	NaBr:Tl powder phosphor prepared from aqueous sol.	10^{-4}	S 268 (3)	S 328 (4)	
2.	" "	10^{-3}	S 268 (3)	S 328 (4)	M 350
3.	" "	10^{-2}	S 268 (5)	S 328 (6)	S S 366, 420
4.	" "	"	S 270 (17)	S 364 (18)	S S 328, 420
5.	" "	"	S 276	S 420 (18)	S S 328, 364
6.	" "	10^{-1}	S 268 (5)	S 328 (6)	S S 366, 420
7.	" "	"	S 270 (19)	S 366 (20)	S S 328, 420
8.	" "	"	S 276 (33)	S 420 (18)	S S 328, 366

Contd...

Sr. No.	Specimen	Tl Conc. in m.f.	Excitation Band (Principal)	Emission	
				Band/ Bands favoured	Other Bands
9.	As-received NaBr:Tl powder phosphor pressed to tablet.	10^{-4}	S 268 (7)	S 328 (8)	S 350
10.	" "	10^{-3}	S 268 (7)	S 328 (8)	S 350, M 420, W 450
11.	" "	10^{-2}	S 270 (21)	S 366 (22)	M 328, S 450.
12.	" "	"	S 274	S 450 (22)	M 328, S 366
13.	" "	10^{-1}	S 272 (23)	S 366 (24)	M 328, S 450
14.	" "	"	S 276	S 450 (24)	M 328, S 366

Contd...

Sr. No.	Specimen	Tl Conc. in m.f.	Excitation Band (Principal)	Emission	
				Band/ Bands favoured	Other Bands
15.	NaBr:Tl powder Phosphor annealed and quenched from 500°C.	10^{-4}	S 268 (9)	S 328 (10)	
16.	" "	10^{-3}	S 268 (9)	S 328 (10)	S 350
17.	" "	10^{-2}	S 270 (25)	S S 390, 420 (26)	M M 450, 500
18.	" "	10^{-1}	S 270 (25)	M 382 (26)	S M M 420, 450, 500
19.	" "	"	S 274 (33)	S 420 (26)	M M M 382, 450, 500

Contd...

Sr. No.	Specimen	Tl Conc. in m.f.	Excitation Band (Principal)	Emission	
				Band/ Bands favoured	Other Bands
20.	NaBr:Tl powder phosphor annealed and quenched from 500°C and then pressed to tablet.	10^{-4}	S 268 (11)	S 328 (12)	S 350
21.	" "	10^{-3}	S 268 (11)	S 328 (12)	M 350
22.	" "	10^{-2}	S 272 (27)	W 380 (28)	S M M 420, 450, 480
23.	" "	"	S 274	S 420 (28)	W M M 380, 450, 480
24.	" "	10^{-1}	S 270 (27)	W 386 (28)	S M M 420, 450, 480
25.	" "	"	S 274	S 420 (28)	W M M 386, 450, 480

Contd...

Sr. No.	Specimen	Tl Conc. in m.f.	Excitation Band (Principal)	Emission	
				Band/ Bands favoured	Other Bands
26.	NaBr:Tl powder phosphor annealed and slowly cooled from 500°C.	10^{-4}	S 268 (13)	S 328 (14)	
27.	" "	10^{-3}	S 268 (13)	S 328 (14)	S 350
28.	" "	10^{-2}	S 278 (29)	S 388 (30)	W 328
29.	" "	10^{-1}	S 272 (29)	W 388 (30)	S M 420, 500
30.	" "	"	S 274 (33)	S 420 (30)	W M 388, 500

Contd...

Sr. No.	Specimen	Tl Conc. in m.f.	Excitation Band (Principal)	Emission	
				Band/ Bands favoured	other Bands
31.	NaBr:Tl powder Phosphor annealed and slowly cooled from 500°C and then pressed to tablet.	10^{-4}	S 268 (15)	S 328 (16)	
32.	" "	10^{-3}	S 268 (15)	S 328 (16)	M 350, S 420
33.	" "	10^{-2}	S 276 (31)	M 378 (32)	W 328, S 420 M 450, W 480
34.	" "	"	S 280	S 420 (32)	W 328, M 378 M 450, W 480
35.	" "	10^{-1}	S 274 (31)	M & S 382, 420 (32)	M 450 M 480

(Figs. : 36 and 37) :

Fig. 36, Curves : 1 and 2 illustrates the excitation spectra of as-received TlBr - powder and TlBr - powder in tabletted form. Fig. 37, Curves : 1 and 2 demonstrates the emission spectra for the above specimens.. It is observed that the excitation spectra in both the cases consist of a broad and diffused band, stretching roughly from 220 to 280 nm . The emission spectrum for any of the specimens is independent of the wavelength of the exciting light. While the excitation spectrum of TlBr does not exhibit well defined maxima, its emission spectra display well discrernible emission band at 360 nm.

(Figs.:38 - 41) :

In yet another series of experiments excitation and emission spectra of (i) aqueous solution of TlBr and (ii) TlBr in saturated aqueous solution of NaBr were examined.. The results obtained are presented in Fig. 40 through 43 . The saturated solution of TlBr exhibits an excitation band around 234 nm , (Fig. 38, Curve : 1) . A broad emission band peaking at 370 nm is observed by

excitation at this wavelength (Fig. 39, Curve : 1). It is seen from the excitation and emission curves for TlBr - solution that the intensity of the excitation as well as the emission band increases with the decrease in the concentration of the solution. The enhancement in the intensity of these bands continues till the solution is diluted to 1:5 (Fig. 38, Curve : 5 and Fig. 39, Curve : 5). With further dilution of the solution, the intensity of the excitation and the emission band begins to drop. It is observed that with the decrease in the concentration of TlBr - solution there is a shift in the position of the excitation and the emission maximum to the short wavelength side, e i.e. from 234 to 220 nm and 370 to 360 nm respectively.

Figs. 40 and 41, Curves : 1 through 6 demonstrate the excitation and emission spectra obtained for aqueous saturated solution of NaBr with addition of TlBr in varying concentration. The excitation spectra for this solution consist of a band at 270 nm when TlBr concentration is low , (Fig. 40, Curve : 1). The band maximum shifts to long-wavelength side as the TlBr concentration is increased, the extreme position recorded

being 286 nm , (Fig. 40, Curve : 6). A subsidiary band around 250 nm also appears at higher TlBr concentration. The emission spectra excited by the bands in the 270 - 286 nm region are presented in Fig. 41 . There is a strong emission band at 460 nm . Alongwith this emission other emission band of lower intensity at 480 nm is also observed when TlBr concentration is very high .

(Figs. : 42 and 43) :

The study of the luminescence spectra of NaBr doped TlBr (TlBr:Na) phosphors has also been carried out. The excitation and emission spectra for TlBr phosphors with 0.3 and 0.5 molar fraction of NaBr are presented in Figs. 42 and 43 . These phosphors were prepared by heating the mixture of TlBr and NaBr powder to around 500°C (i.e. beyond the melting point of TlBr) and then quenching the mixture to room temperature. It is quite apparent that there is a marked difference between the excitation spectra of TlBr:Na specimen and undoped TlBr - powder. The former display selective

excitation band around 280 nm whereas the latter exhibit a broad and diffused excitation spectrum. In the same manner, the spectral composition for the emission of TlBr:Na phosphor differs widely from that of undoped TlBr. The emission of TlBr is only in the near - ultraviolet region whereas with the introduction of NaBr in TlBr, the emission extends far into the visible region around 500 nm . This emission becomes more prominent if the concentration of NaBr in TlBr is increased (Fig.. 43). The results obtained are summarised in Table 2.

TABLE : 2 :

Excitation and Emission Bands in NaBr Doped TlBr (TlBr:Na) Phosphors.

Sr. No.	Specimen	Na Conc. in m.f.	Excitation Band(Prin.)	Emission	
				Band/ Bands favoured	Other Bands
1.	TlBr:Na powder phosphor.	0.3	S 270 (42)	W 360 (43)	S 460, S 500
2.	" "	"	S 274 (42)	S 460 (43)	W 360, S 500
3.	" "	"	S 280 (42)	S 500 (43)	W 360, S 460
4.	" "	0.5	S 270 (42)	W 370 (43)	S 460, S 500
5.	" "	"	S 278 (42)	S 460 (43)	W 370, S 500
6.	" "	"	S 280 (42)	S 500 (43)	W 370, S 460

Fig. 1(a) : Excitation spectra of undoped NaBr-powder specimen for 360 nm emission.

Curve : 1 - Specimen annealed and quenched from 500°C (in vacuum)

Curve : 2 - Specimen annealed and quenched from 500°C (in open air)

Curve : 3 - Specimen annealed and quenched from 650°C (in open air)

Scale on the left hand side corresponds to curve : 1

Scale on the right hand side corresponds to curves: 2 & 3

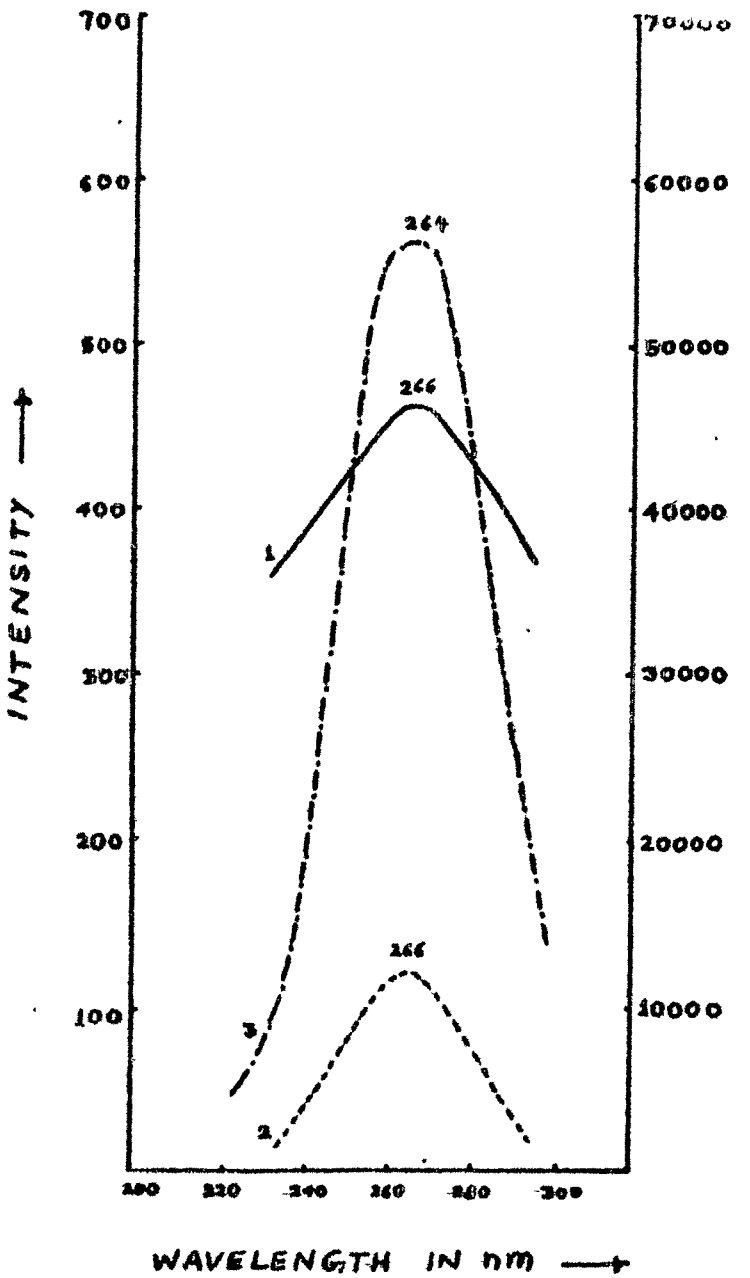

700
600
500
400
300
200
100
70000
60000
50000
40000
30000
20000
10000
INTENSITY
264
266
266
1
2
3
WAVELENGTH IN nm

FIG. 1a

Fig. 1(b) : Excitation spectra of undoped NaBr specimen for 360 nm emission.

Curve : 1 - Specimen annealed and quenched from 500°C (in vacuum) and then compressed to tablet.

Curve : 2 - Specimen annealed and quenched from 500°C (in open air) and then compressed to tablet.

Curve : 3 - Specimen annealed and quenched from 650°C (in open air) and then compressed to tablet.

Scale on the left hand side corresponds to Curve : 1

Scale on the right hand side corresponds to Curves : 2 & 3

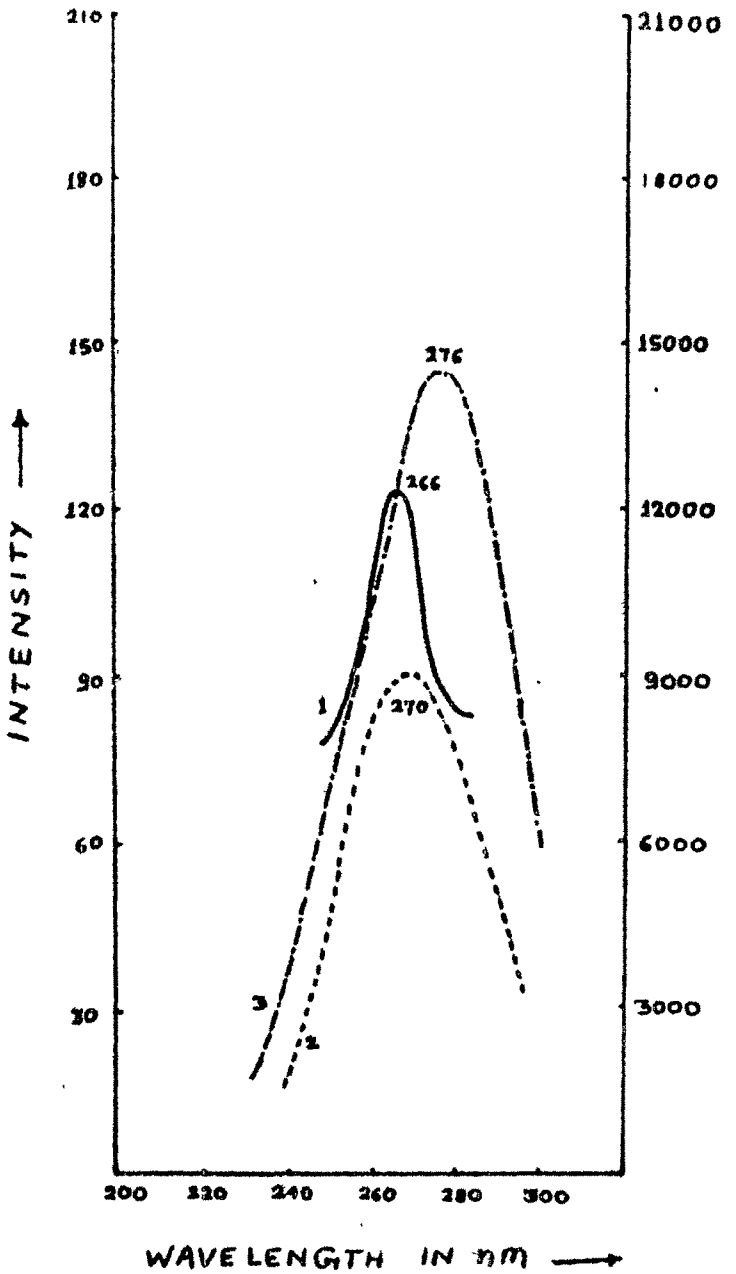

210
180
150
120
90
60
30
21000
18000
15000
12000
9000
6000
3000
INTENSITY
276
266
270
1
2
3
200
220
240
260
280
300
WAVE LENGTH IN nm

FIG. 1b

Fig. 2(a) : Emission spectra of undoped NaBr-powder specimens on excitation at corresponding wavelengths as observed from curves in Fig. 1(a).

Curve : 1 - Specimen annealed and quenched from 500°C (in vacuum)

Curve : 2 - Specimen annealed and quenched from 500°C (in open air)

Curve : 3 - Specimen annealed and quenched from 650°C (in open air)

Scale on the left hand side corresponds to curve : 1

Scale on the right hand side corresponds to curves : 2 & 3

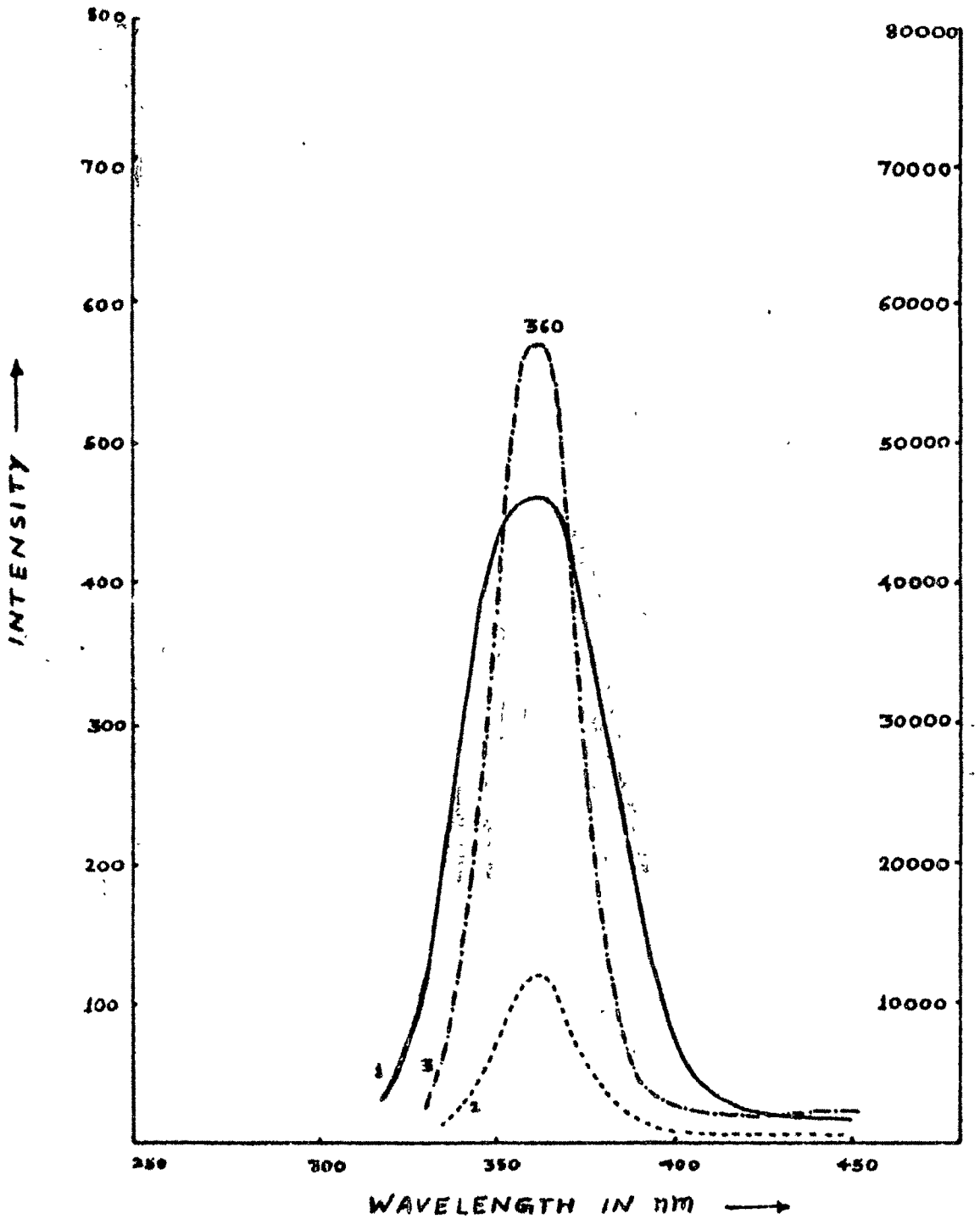

800
700
600
500
400
300
200
100
80000
70000
60000
50000
40000
30000
20000
10000
360
1
3
2
250
300
350
400
450
INTENSITY
WAVELENGTH IN nm

FIG. 2a

Fig. 2(b) : Emission spectra of undoped NaBr specimen on excitation at corresponding wavelengths as observed from curves in Fig. 2(a).

Curve : 1 - Specimen annealed and quenched from 500°C (in vacuum) and then compressed to tablet.

Curve : 2 - Specimen annealed and quenched from 500°C (in open air) and then compressed to tablet.

Curve : 3 - Specimen annealed and quenched from 650°C (in open air) and then compressed to tablet.

Scale on the left hand side corresponds to Curve : 1

Scale on the right hand side corresponds to Curves : 2 & 3

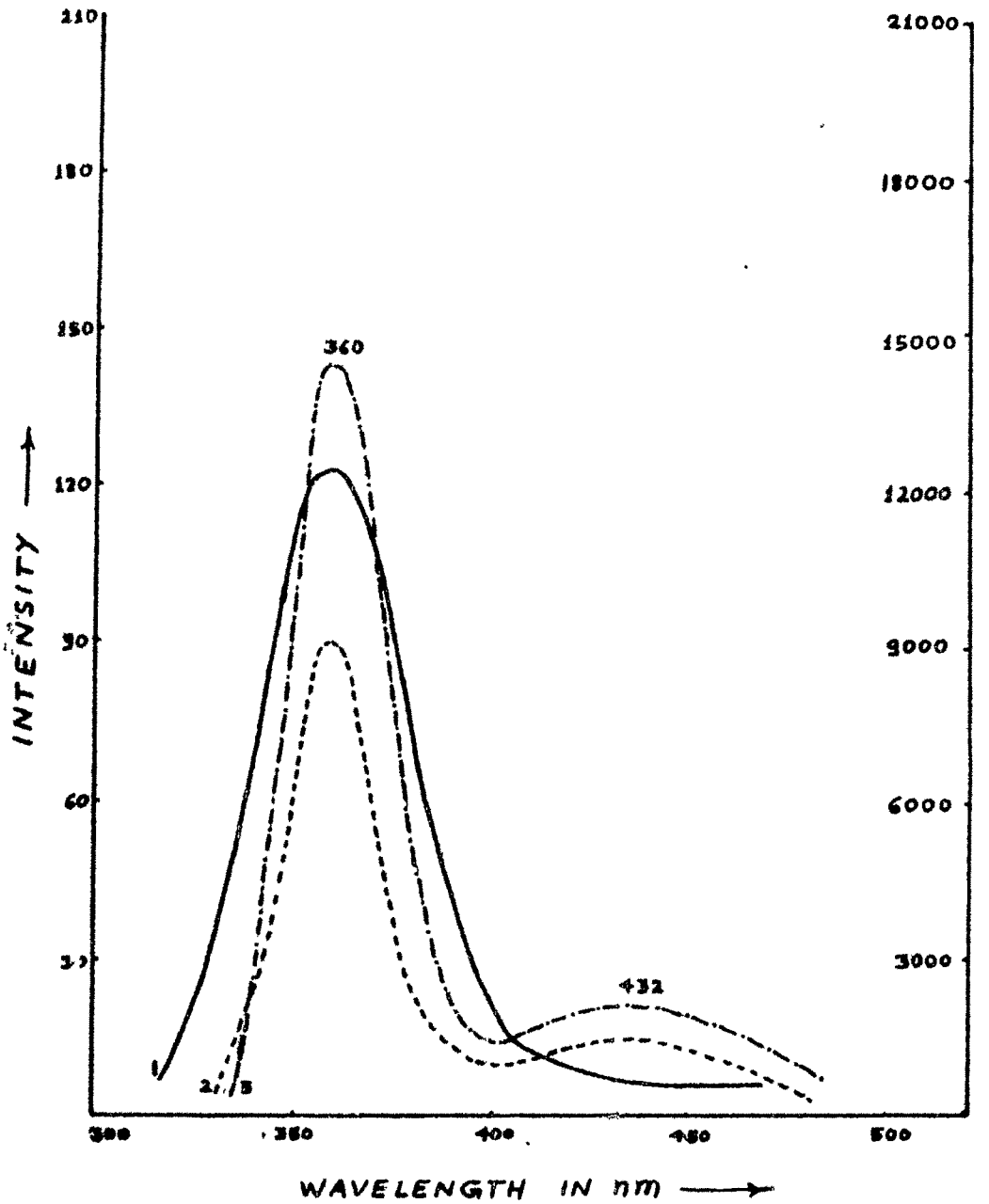

210
180
150
120
90
60
30
21000
18000
15000
12000
9000
6000
3000
360
432
2
3
INTENSITY
300
350
400
450
500
WAVELENGTH IN nm

FIG. 26

Fig. 3 : Excitation spectra of NaBr:Tl powder specimens for 328 nm emission.

Specimens as-received by crystallization from aqueous solution.

Curve : 1 - Tl concentration $\sim 10^{-4}$ m.f.

Curve : 2 - Tl concentration $\sim 10^{-3}$ m.f.

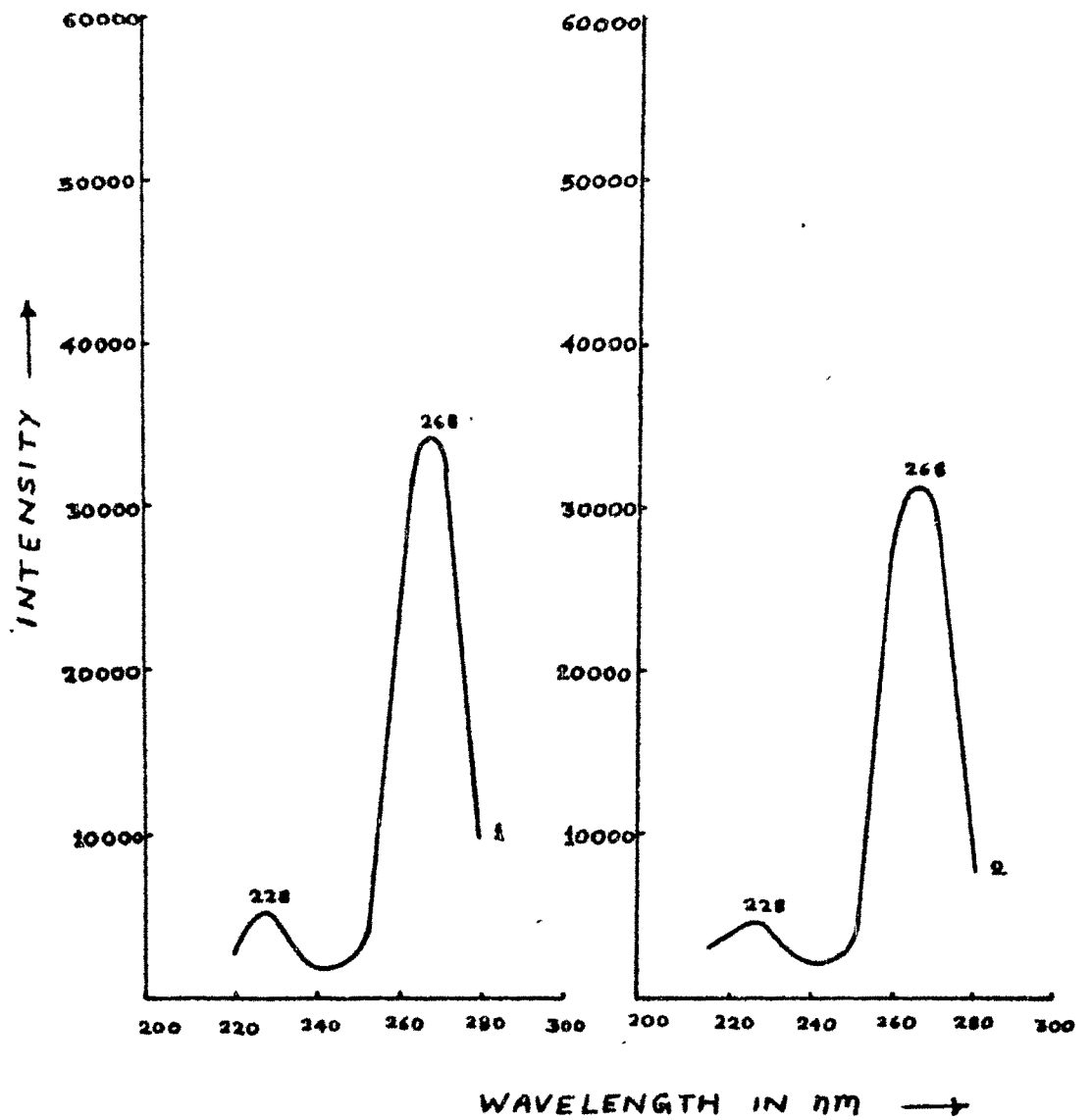

60000
50000
40000
30000
20000
10000
INTENSITY
268
228
1
200
220
240
260
280
300
60000
50000
40000
30000
20000
10000
266
228
2
200
220
240
260
280
300
WAVELENGTH IN nm

FIG. 3

Fig. 4 : Emission spectra of NaBr:Tl powder specimens upon excitation at 268 nm.

Specimens as-received by crystallization from aqueous solution.

Curve : 1 - Tl concentration $\sim 10^{-4}$ m.f.

Curve : 2 - Tl concentration $\sim 10^{-3}$ m.f.

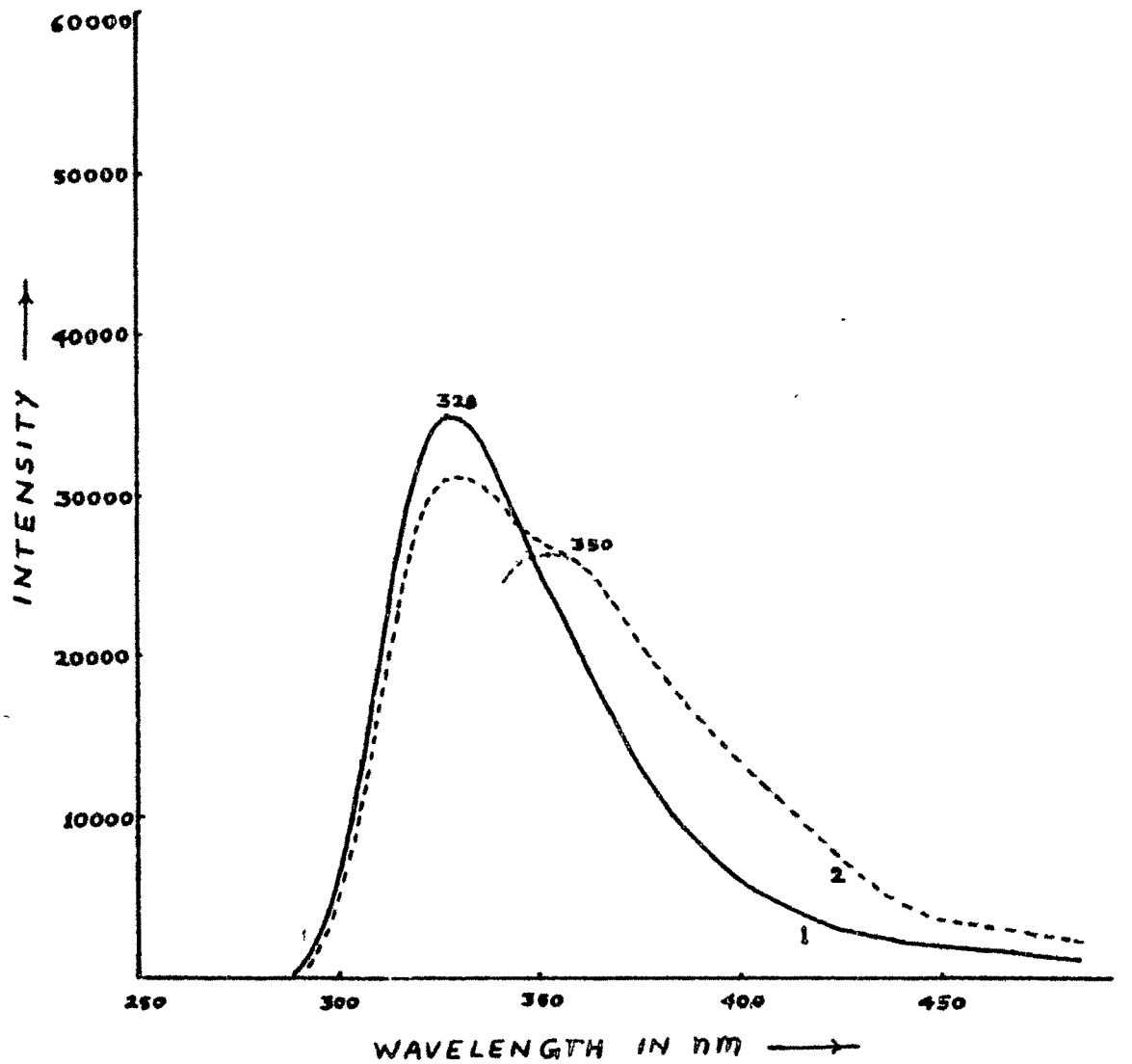

60000
50000
40000
30000
20000
10000
INTENSITY
328
350
2
1
250
300
350
400
450
WAVELENGTH IN nm

FIG. 4

Fig. 5 : Excitation spectra of NaBr:Tl powder specimens for 328 nm emission.

Specimens as-received by crystallization from aqueous solution.

Curve : 1 - Tl concentration $\sim 10^{-2}$ m.f.

Curve : 2 - Tl concentration $\sim 10^{-1}$ m.f.

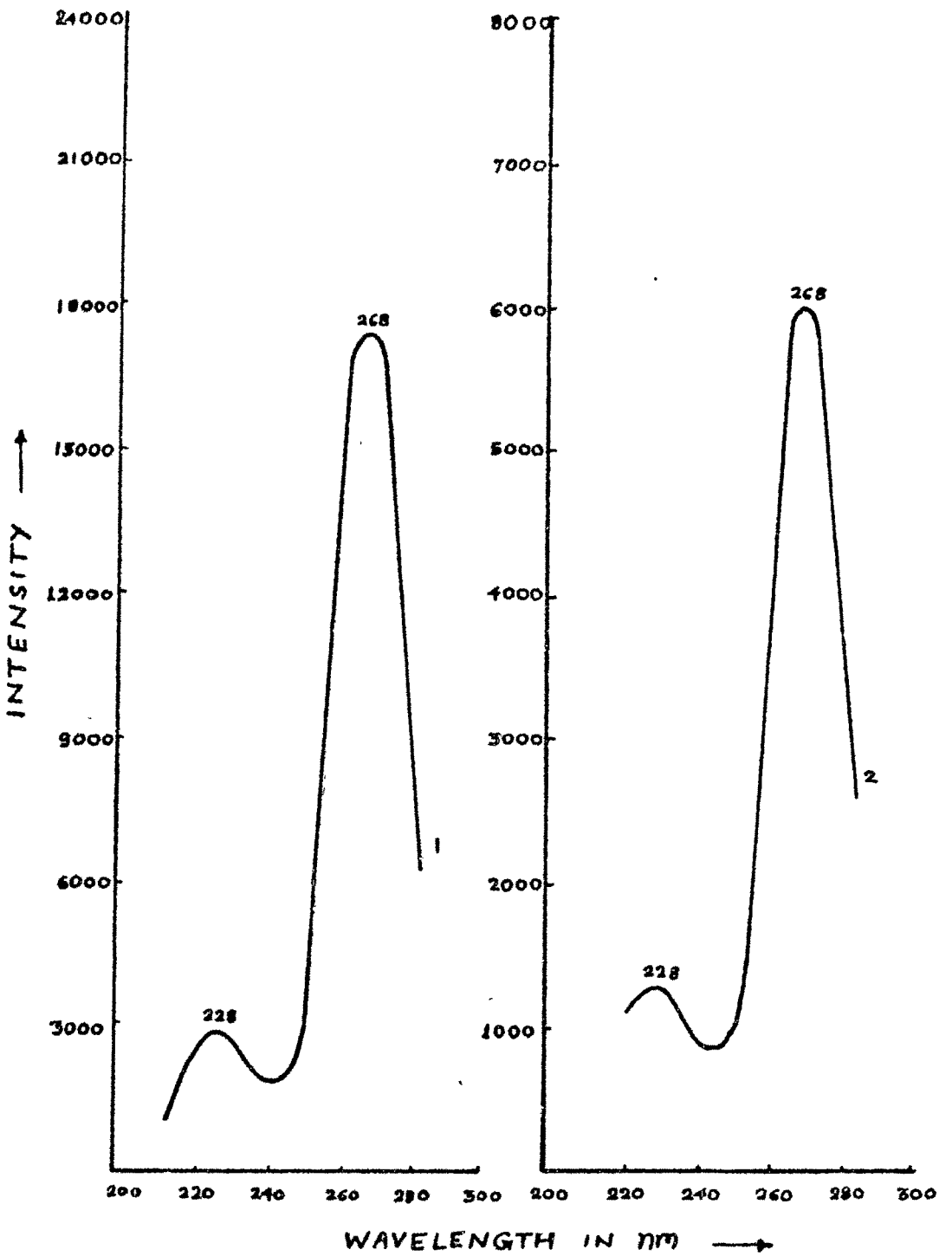

24000
21000
18000
15000
12000
9000
6000
3000
INTENSITY
268
228
1
200
220
240
260
280
300
8000
7000
6000
5000
4000
3000
2000
1000
268
228
2
200
220
240
260
280
300
WAVELENGTH IN nm

FIG. 5

Fig. 6 : Emission spectra of NaBr:Tl powder specimens upon excitation at 268 nm.

Specimens as-received by crystallization from aqueous solution.

Curve : 1 - Tl concentration $\sim 10^{-2}$ m.f.

Curve : 2 - Tl concentration $\sim 10^{-1}$ m.f.

Scale on the left hand side corresponds to Curve : 1

Scale on the right hand side corresponds to Curve : 2

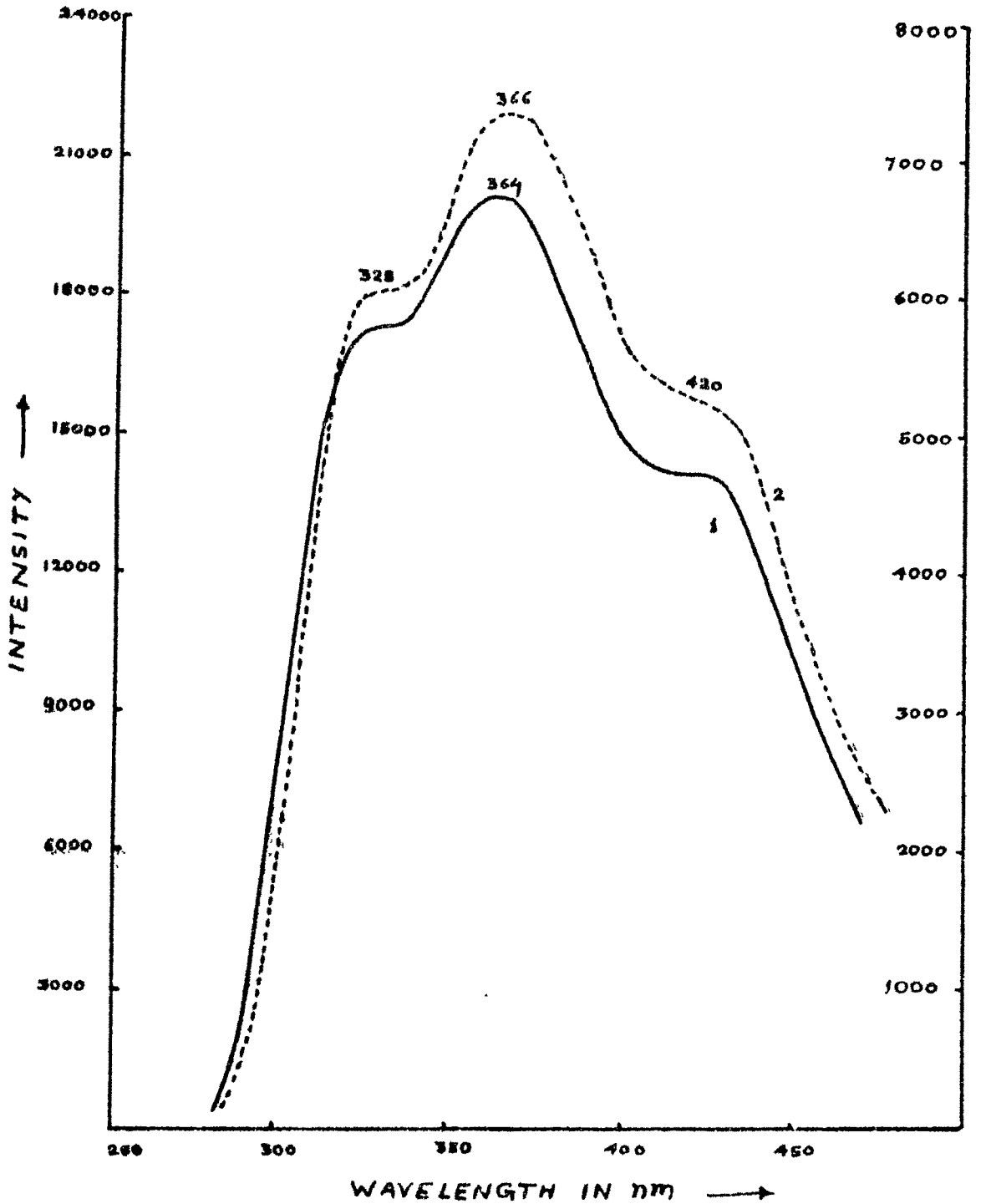

24000
21000
18000
15000
12000
9000
6000
3000
8000
7000
6000
5000
4000
3000
2000
1000
366
364
328
420
2
1
INTENSITY
250
300
350
400
450
WAVELENGTH IN nm

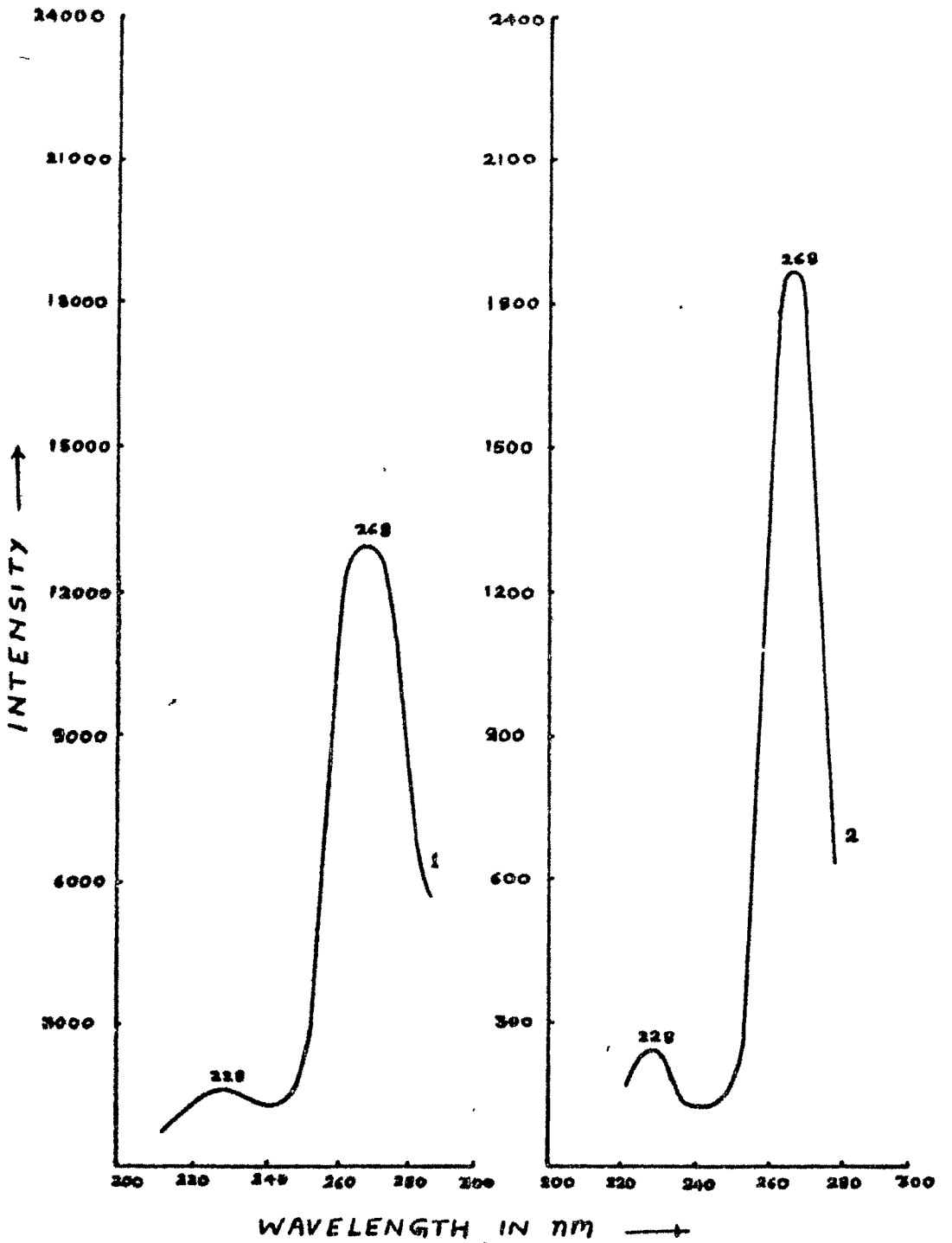
FIG. 6

Fig. 7 : Excitation spectra of NaBr:Tl specimens for 328 nm emission.

Specimens as-received from solution and then compressed to tablet.

Curve : 1 - Tl concentration $\sim 10^{-4}$ m.f.

Curve : 2 - Tl concentration $\sim 10^{-3}$ m.f.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21000
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12000
9000
6000
3000
INTENSITY
268
228
1
2400
2100
1800
1500
1200
900
600
300
268
229
2
200
220
240
260
280
300
WAVELENGTH IN nm

FIG. 7

Fig. 8 : Emission spectra of NaBr:Tl specimens upon excitation at 268 nm.

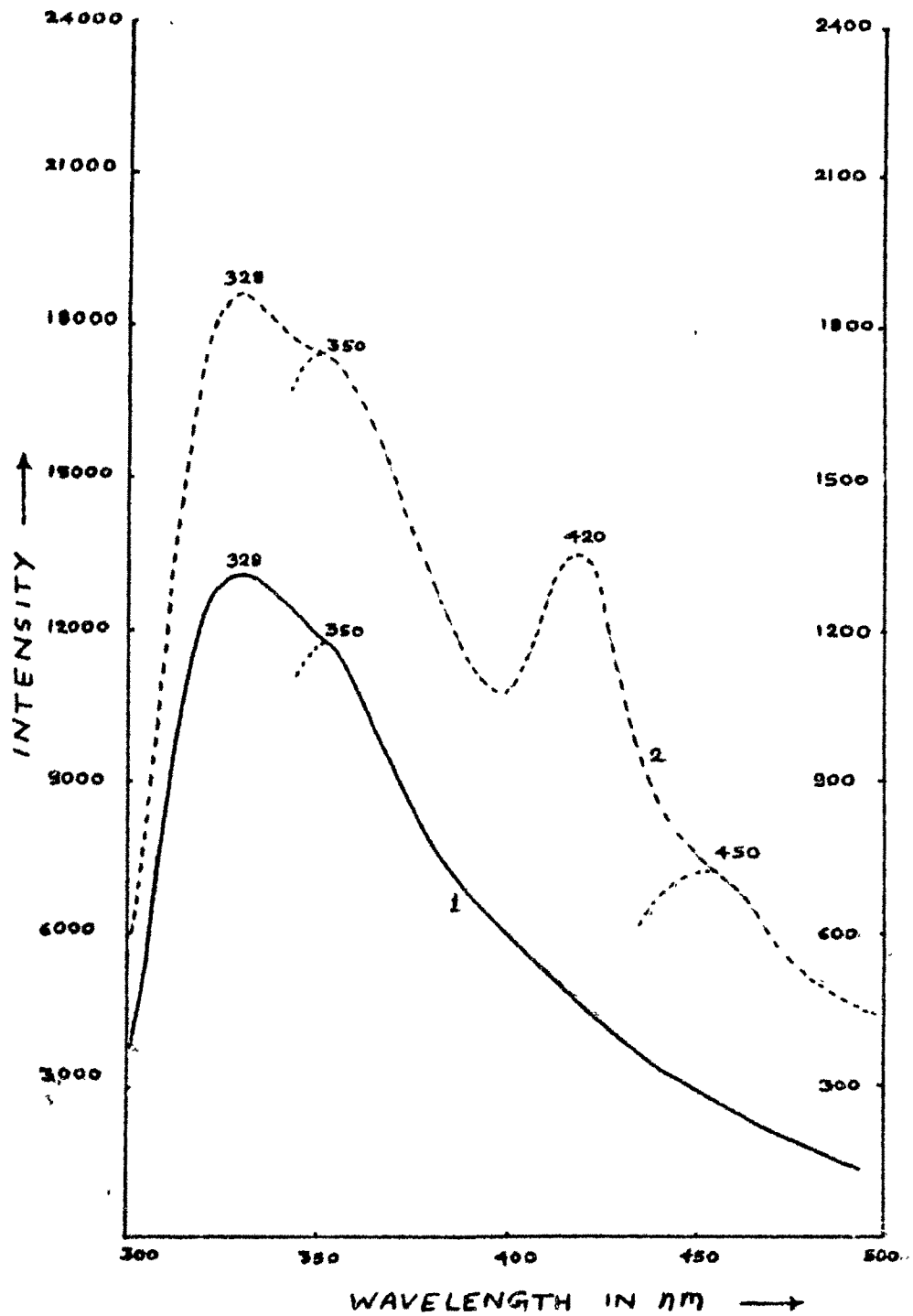
Specimens as-received from solution and then compressed to tablet.

Curve : 1 - Tl concentration $\sim 10^{-4}$ m.f.

Curve : 2 - Tl concentration $\sim 10^{-3}$ m.f.

Scale on the left hand side corresponds to Curve : 1

Scale on the right hand side corresponds to Curve : 2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2100
1800
1500
1200
900
600
300
INTENSITY
328
350
328
350
420
450
2
1
300
350
400
450
500
WAVELENGTH IN nm

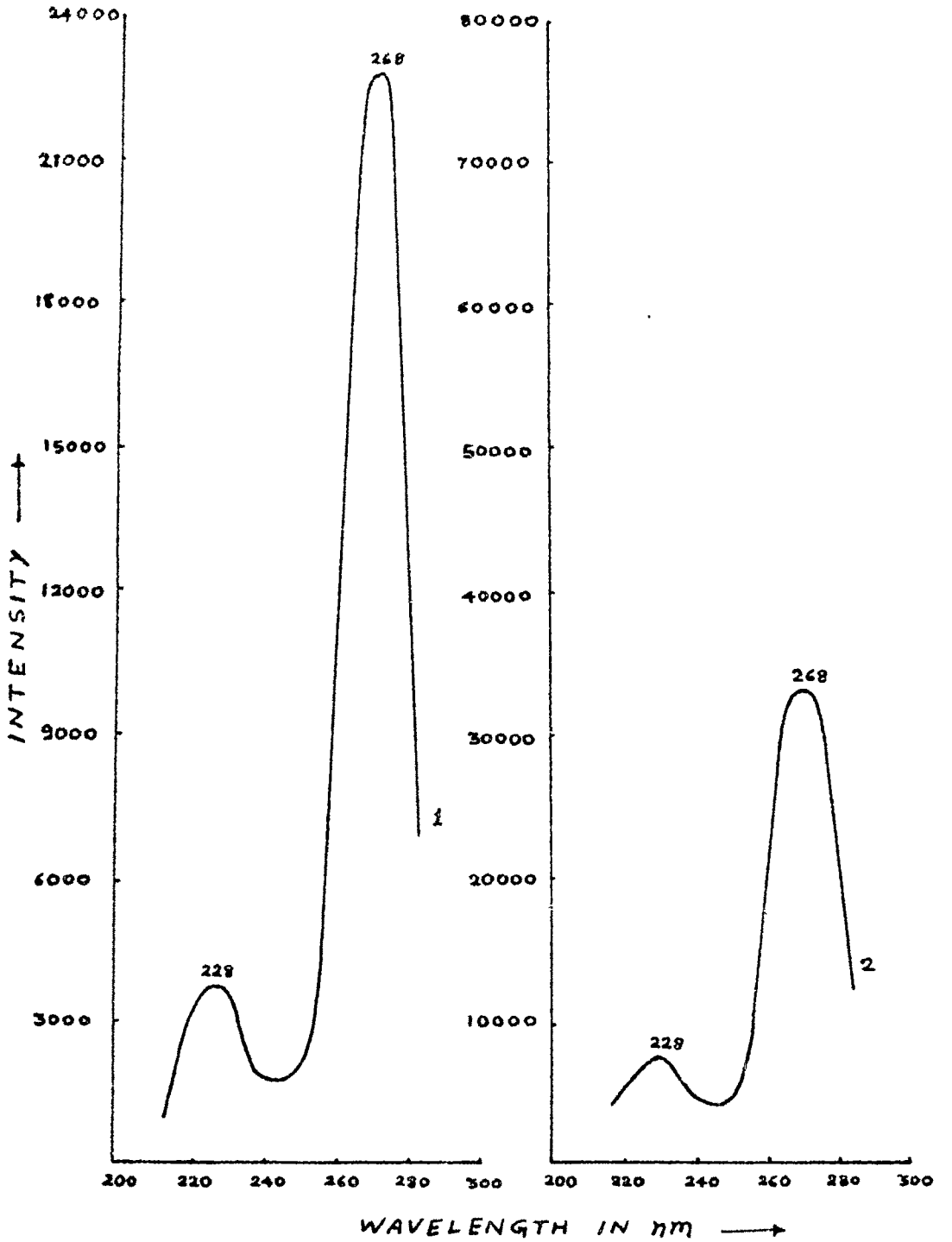
FIG. 8

Fig. 9 : Excitation spectra of NaBr:Tl powder specimens for 328 nm emission.

Specimens annealed at 500°C for 4 hours in evacuated and sealed tube and quenched rapidly to room temperature.

Curve : 1 - Tl concentration $\sim 10^{-4}$ m.f.

Curve : 2 - Tl concentration $\sim 10^{-3}$ m.f.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60000
50000
40000
30000
20000
10000
268
228
1
2
200
220
240
260
280
300
WAVELENGTH IN nm

FIG. 9

Fig. 10 : Emission spectra of NaBr:Tl powder specimens upon excitation at 268 nm.

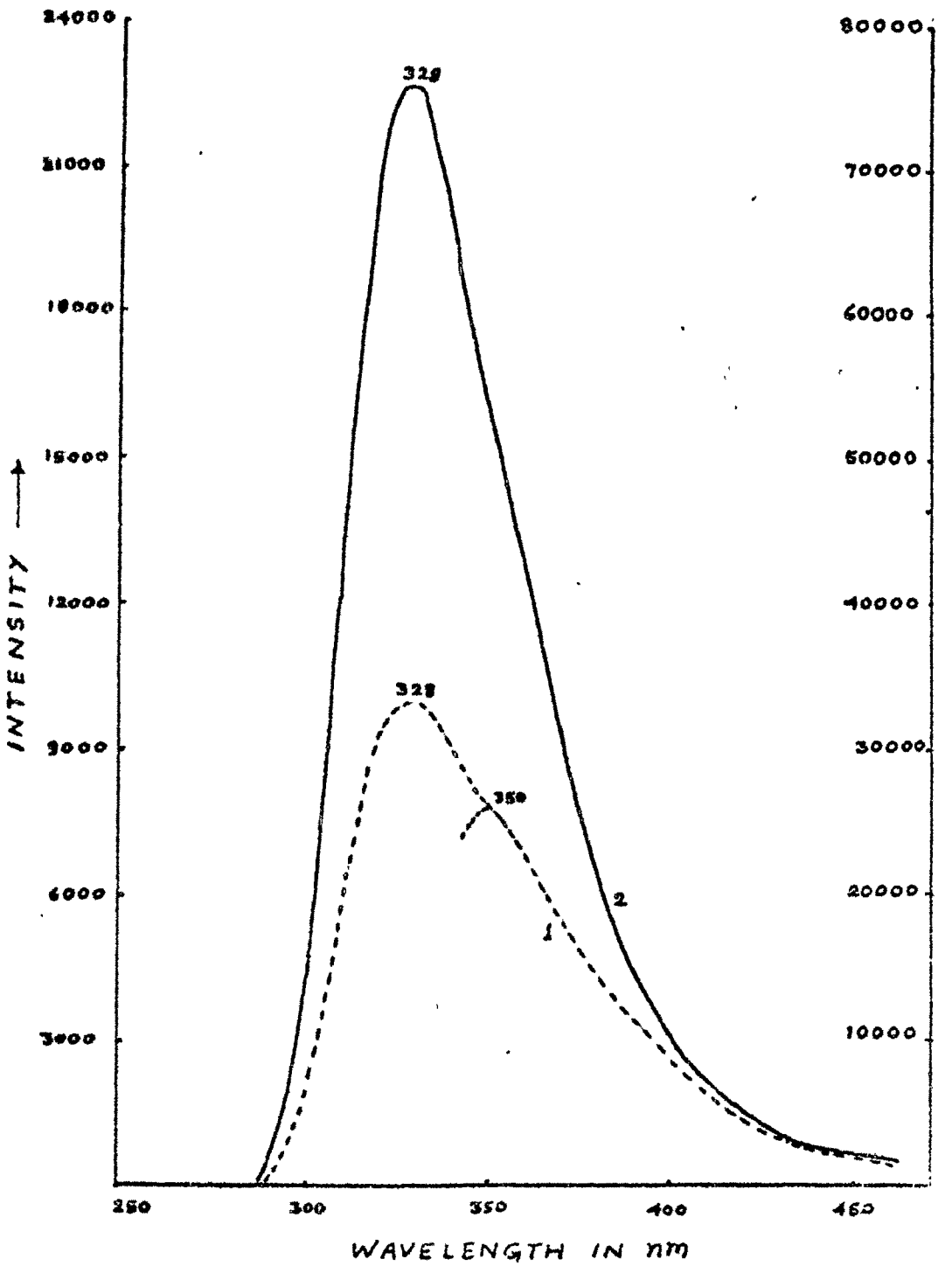
Specimens annealed at 500°C for 4 hours in evacuated and sealed tube and quenched rapidly to room temperature.

Curve : 1 - Tl concentration $\sim 10^{-4}$ m.f.

Curve : 2 - Tl concentration $\sim 10^{-3}$ m.f.

Scale on the left hand side corresponds to Curve : 1

Scale on the right hand side corresponds to Curve : 2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80000
70000
60000
50000
40000
30000
20000
10000
INTENSITY
328
328
350
2
1
250
300
350
400
450
WAVELENGTH IN nm

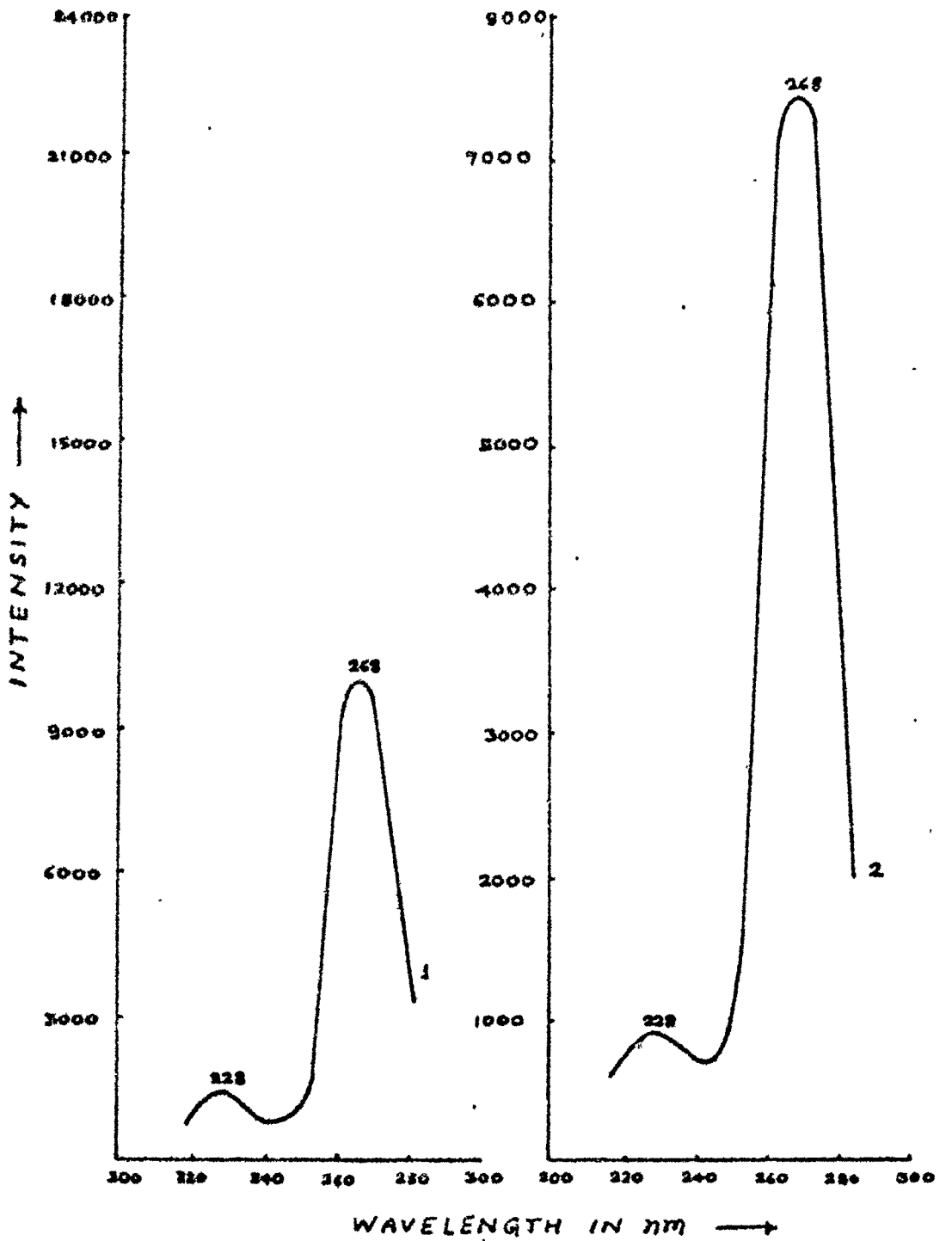
FIG. 10

Fig. 11 : Excitation spectra of NaBr:Tl specimens for 328 nm emission.

Specimens annealed at 500°C for 4 hours in evacuated and sealed tube, quenched rapidly to room temperature and subsequently compressed to tablet.

Curve : 1 - Tl concentration $\sim 10^{-4}$ m.f.

Curve : 2 - Tl concentration $\sim 10^{-3}$ m.f.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INTENSITY
268
228
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9000
7000
6000
5000
4000
3000
2000
1000
268
228
2
300
320
340
360
380
400
WAVELENGTH IN nm

FIG. 11

Fig. 12 : Emission spectra of NaBr:Tl specimens for 328 nm emission

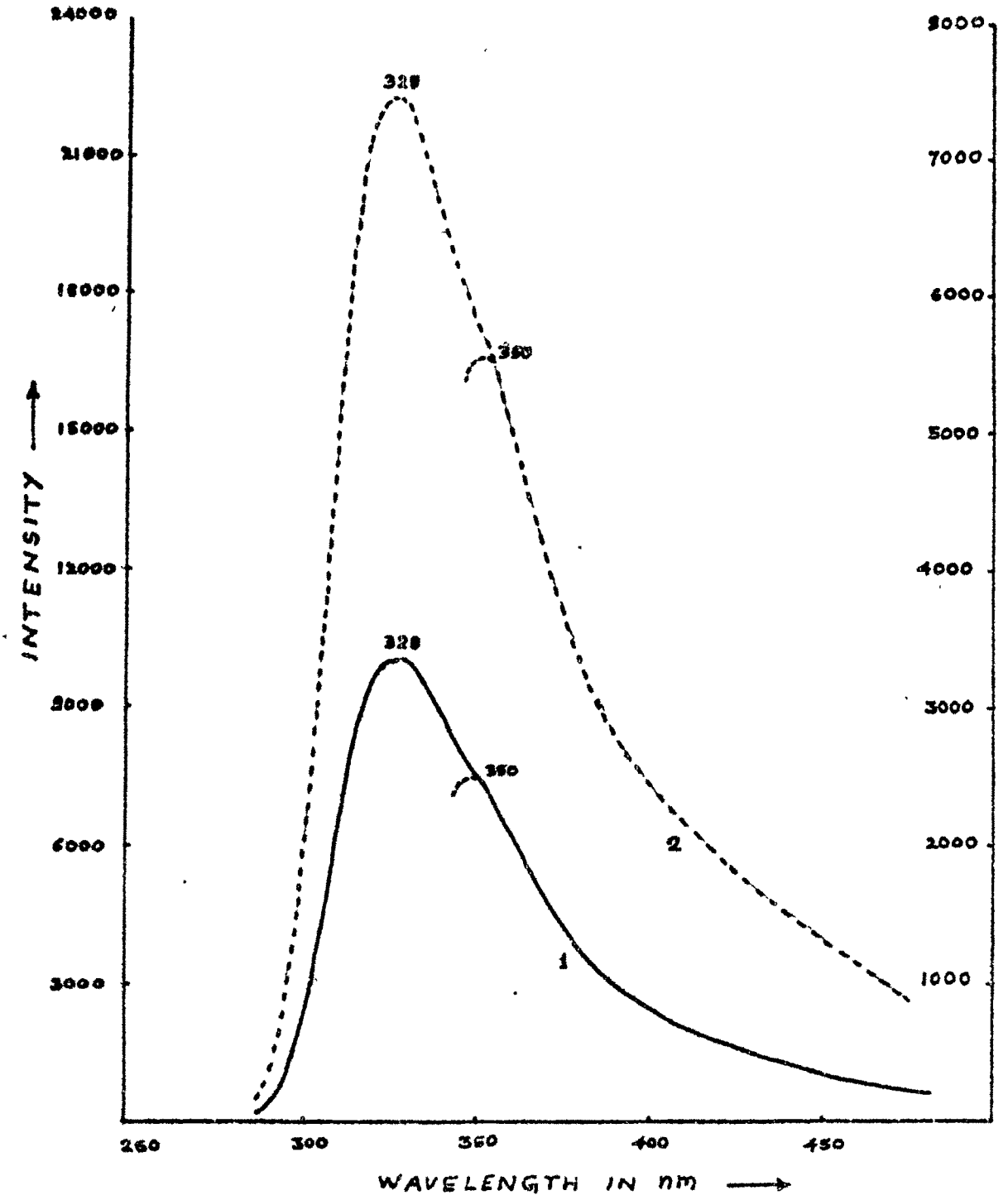
Specimens annealed at 500°C for 4 hours in evacuated and sealed tube, quenched rapidly to room temperature and subsequently compressed to tablet.

Curve : 1 - Tl concentration $\sim 10^{-4}$ m.f.

Curve : 2 - Tl concentration $\sim 10^{-3}$ m.f.

Scale on the left hand side corresponds to curve : 1

Scale on the right hand side corresponds to curve : 2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6000
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INTENSITY
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7000
6000
5000
4000
3000
2000
1000
328
350
328
350
2
1
260
300
350
400
450
WAVELENGTH IN nm

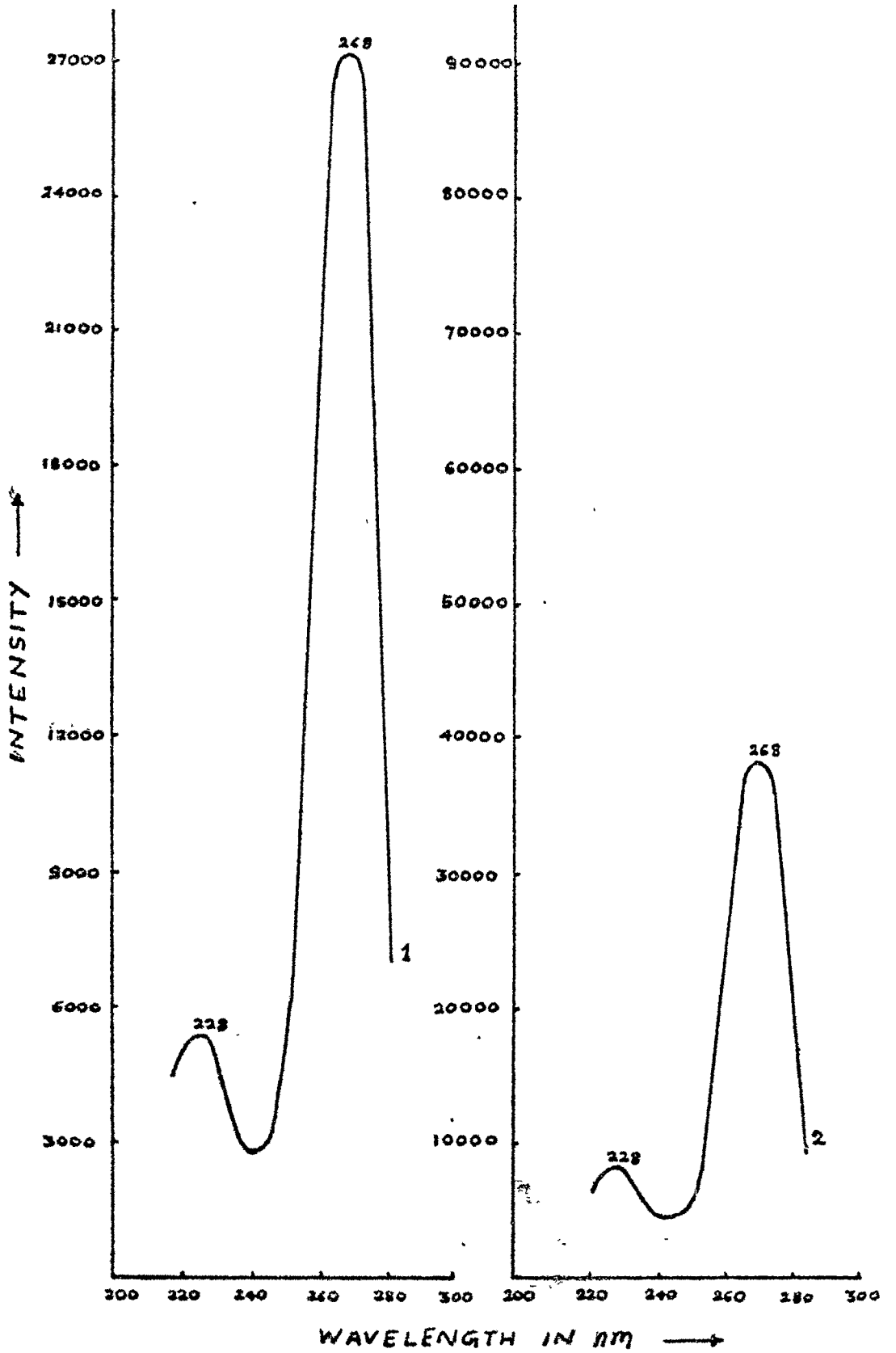
FIG. 12

Fig. 13 : Excitation spectra of NaBr:Tl specimens for 328 nm emission.

Specimens annealed at 500°C for 4 hours in evacuated sealed tube and slowly cooled to room temperature.

Curve : 1 - Tl concentration $\sim 10^{-4}$ m.f.

Curve : 2 - Tl concentration $\sim 10^{-3}$ m.f.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9000
6000
3000
INTENSITY
268
228
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90000
80000
70000
60000
50000
40000
30000
20000
10000
268
228
2
200
220
240
260
280
300
WAVELENGTH IN nm

FIG. 13

Fig. 14 : Emission spectra of NaBr:Tl specimens upon excitation at 268 nm .

Specimens annealed at 500°C for 4 hours in evacuated and sealed tube and slowly cooled to room temperature.

Curve : 1 - Tl concentration $\sim 10^{-4}$ m.f.

Curve : 2 - Tl concentration $\sim 10^{-3}$ m.f.

Scale on the left hand side corresponds to Curve : 1

Scale on the right hand side corresponds to Curve : 2

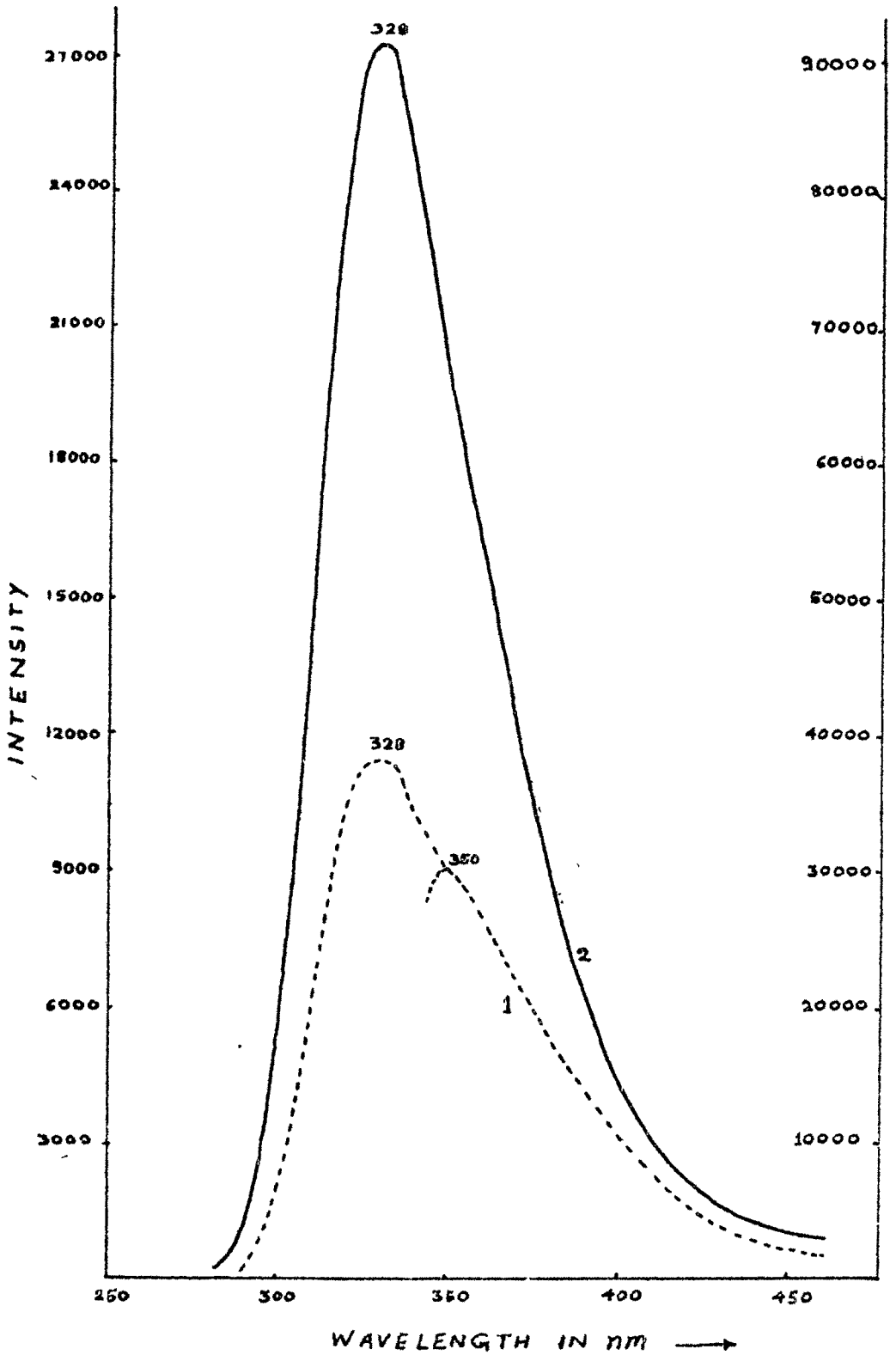

328
328
350
2
1
27000
24000
21000
18000
15000
12000
9000
6000
3000
90000
80000
70000
60000
50000
40000
30000
20000
10000
INTENSITY
250
300
350
400
450
WAVELENGTH IN nm

FIG 14

Fig. 15 : Excitation spectra of NaBr:Tl specimens for 328 nm emission.

Specimens annealed at 500°C for 4 hours in evacuated and sealed tube, slowly cooled to room temperature and subsequently compressed to tablet.

Curve : 1 - Tl concentration $\sim 10^{-4}$ m.f.

Curve : 2 - Tl concentration $\sim 10^{-3}$ m.f.

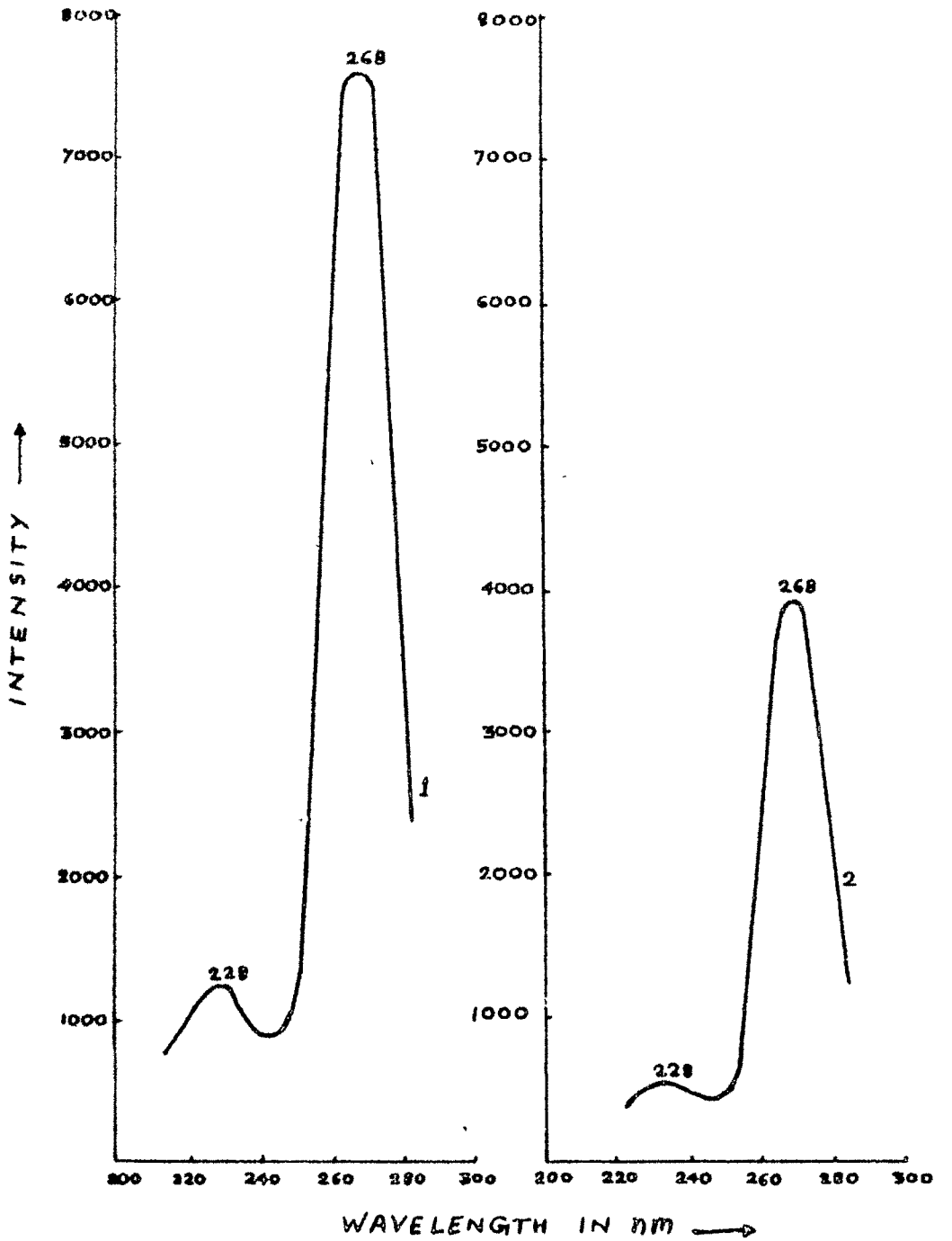

8000
7000
6000
5000
4000
3000
2000
1000
INTENSITY
268
228
1
2
200
220
240
260
280
300
WAVELENGTH IN nm

FIG. 15

Fig. 16 : Emission spectra of NaBr:Tl specimens upon excitation at 268 nm.

Specimens annealed at 500°C for 4 hours in evacuated and sealed tube, slowly cooled at room temperature, and subsequently compressed to tablet.

Curve : 1 - Tl concentration $\sim 10^{-4}$ m.f.

Curve : 2 - Tl concentration $\sim 10^{-3}$ m.f.

Scale on the left hand side corresponds to Curve : 1

Scale on the right hand side corresponds to Curve : 2

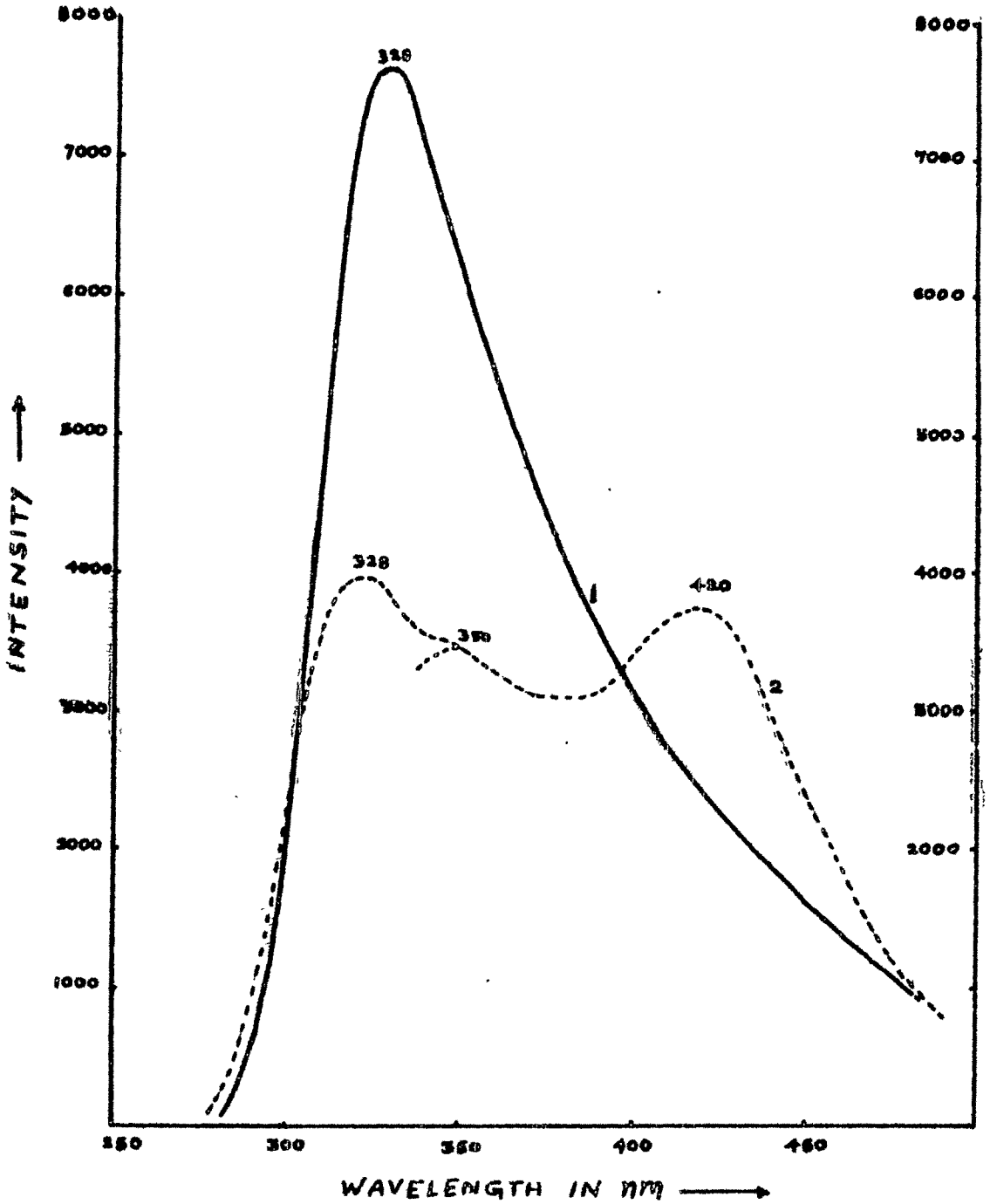

8000
7000
6000
5000
4000
3000
2000
1000
INTENSITY
328
328
350
430
1
2
150
300
350
400
450
WAVELENGTH IN nm

FIG. 16

Fig. 17 : Excitation spectra of NaBr:Tl powder specimens for at emission at 364 nm (Curve : 1) and at 378 nm (Curve : 2).

Specimens as-received by crystallization from aqueous solution.

Tl concentration $\sim 10^{-2}$ m.f.

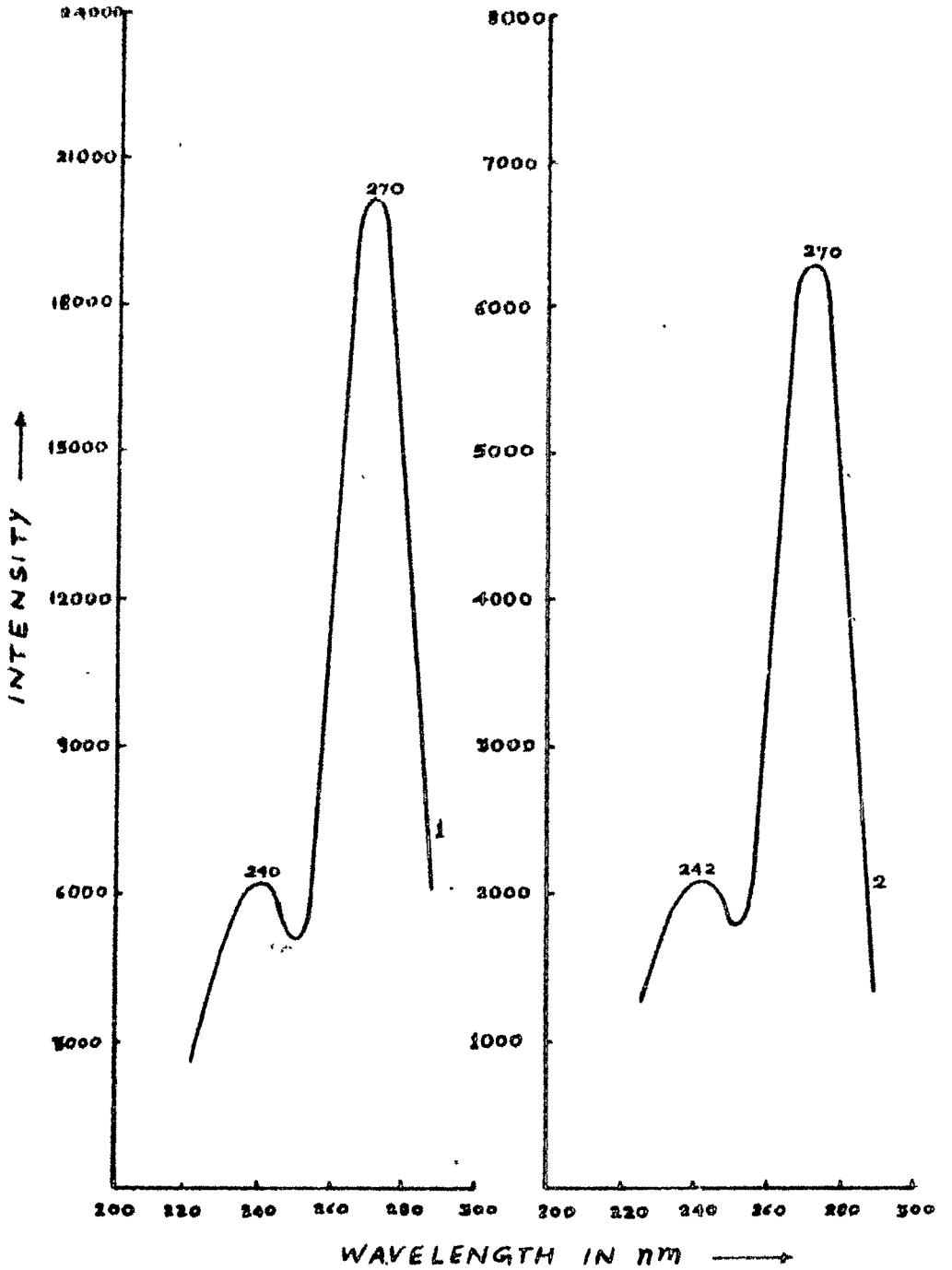


FIG. 17

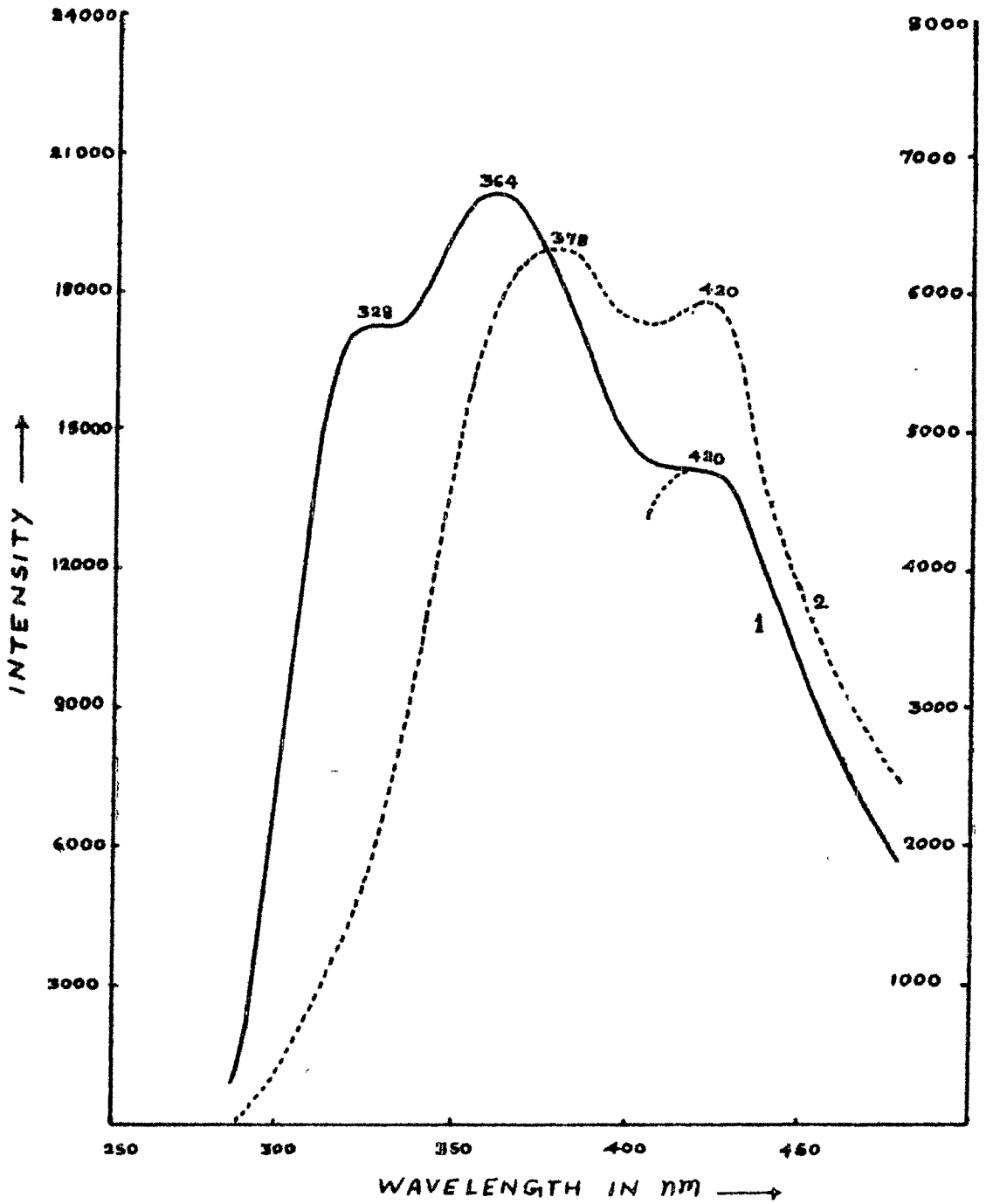
Fig. 18 : Emission spectra of NaBr:Tl powder specimen upon excitation at 270 nm (Curve : 1) and at 242 nm (Curve : 2).

Specimens as-received by crystallization from aqueous solution.

Tl concentration $\sim 10^{-2}$ m.f.

Scale on the left hand side corresponds to Curve : 1

Scale on the right hand side corresponds to Curve : 2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9000
6000
3000
8000
7000
6000
5000
4000
3000
2000
1000
INTENSITY
364
378
328
420
420
1
2
250
300
350
400
450
WAVELENGTH IN nm

FIG. 18

Fig. 19 : Excitation spectra of NaBr:Tl powder specimen for emission at 366 nm (Curve : 1) and at 380 nm (Curve :2).

Specimens as-received by crystallization from aqueous solution.

Tl concentration $\sim 10^{-1}$ m.f.

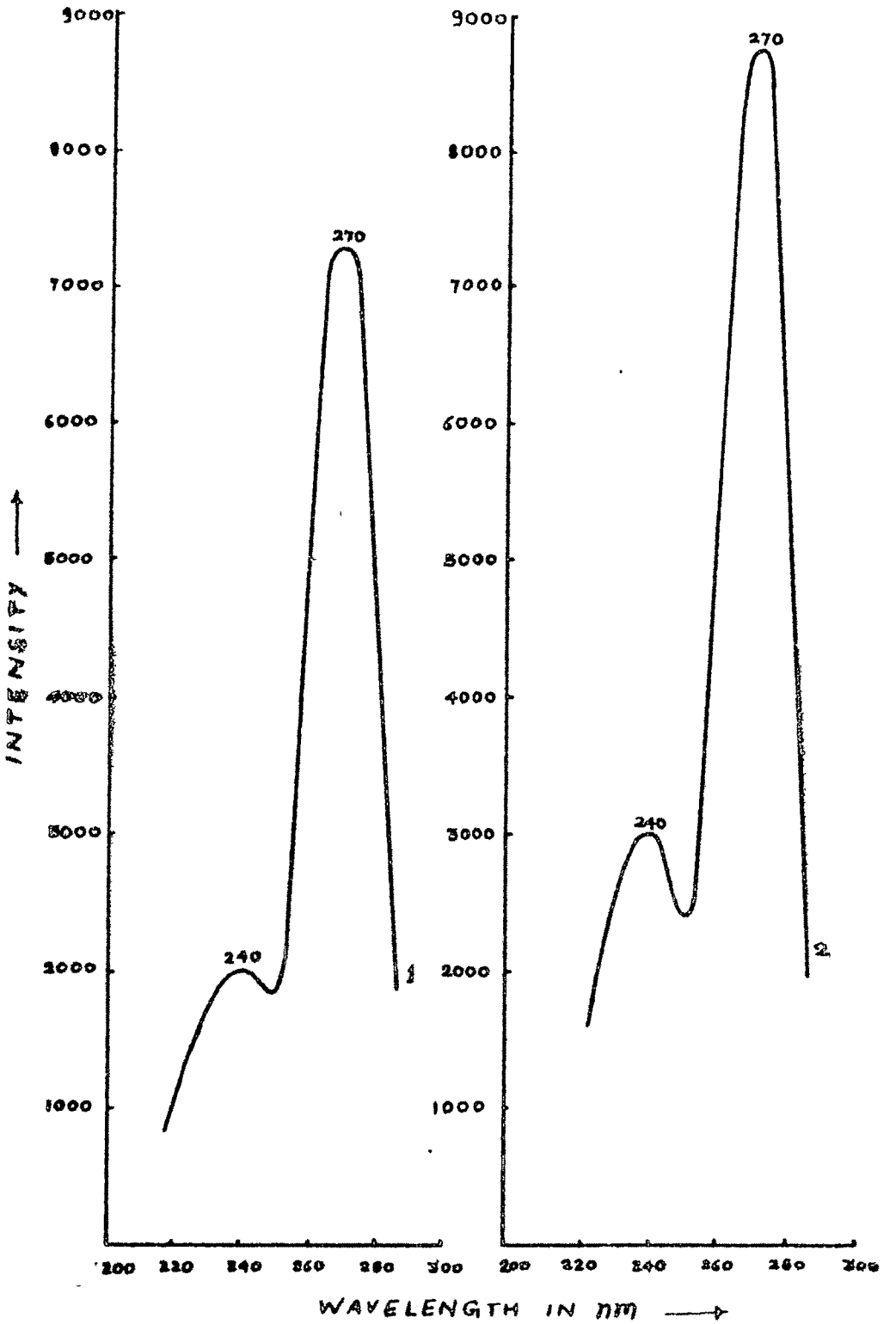

9000
8000
7000
6000
5000
4000
3000
2000
1000
INTENSITY
270
240
1
2
200
220
240
260
280
300
WAVELENGTH IN nm

FIG. 19

Fig. 20 : Emission spectra of NaBr:Tl powder specimen upon excitation at 270 nm (Curve : 1) and at 240 nm (Curve : 2).

Specimens as-received by crystallization from aqueous solution.

Tl concentration $\sim 10^{-1}$ m.f.

Scale on the left hand side corresponds to Curve : 1

Scale on the right hand side corresponds to Curve : 2

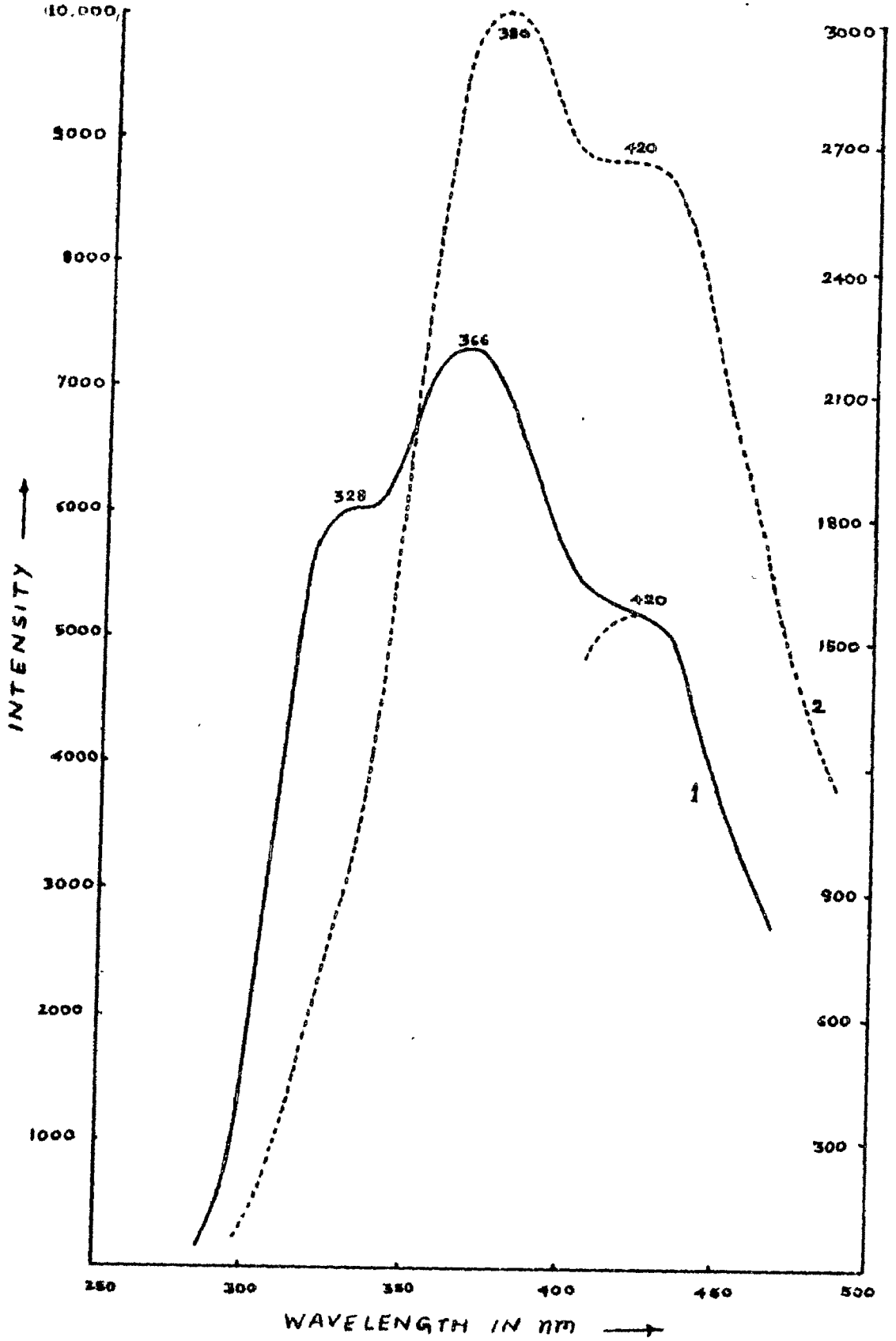
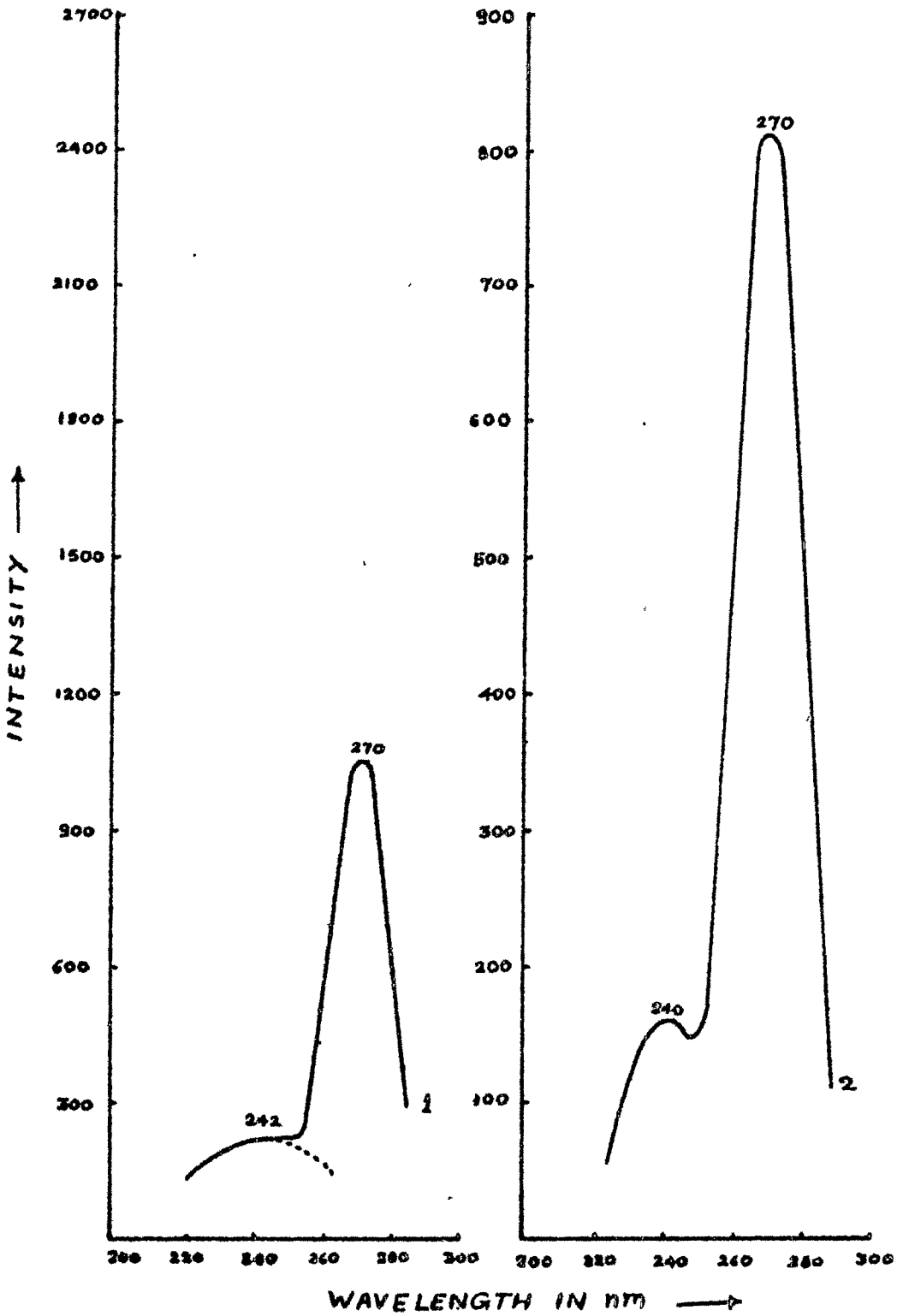

10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
INTENSITY
3000
2700
2400
2100
1800
1500
900
600
300
386
420
366
328
420
1
2
250
300
350
400
450
500
WAVELENGTH IN nm

FIG. 20

Fig. 21 : Excitation spectra of NaBr:Tl specimen for emission at 366 nm (Curve : 1) and at 386 nm (Curve : 2).

Specimens as-received by crystallization from aqueous solution and then compressed to tablet.

Tl concentration $\sim 10^{-2}$ m.f.


2700
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2100
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1500
1200
900
600
300
INTENSITY
270
242
1
900
800
700
600
500
400
300
200
100
270
240
2
200 220 240 260 280 300
200 220 240 260 280 300
WAVELENGTH IN nm

FIG. 21

Fig. 22 : Emission spectra of NaBr:Tl specimen upon excitation at 270 nm (Curve : 1) and at 240 nm (Curve : 2).

Specimens as-received by crystallization from aqueous solution and then compressed to tablet.

Tl concentration $\sim 10^{-2}$ m.f.

Scale on the left hand side corresponds to Curve : 1

Scale on the right hand side corresponds to Curve : 2

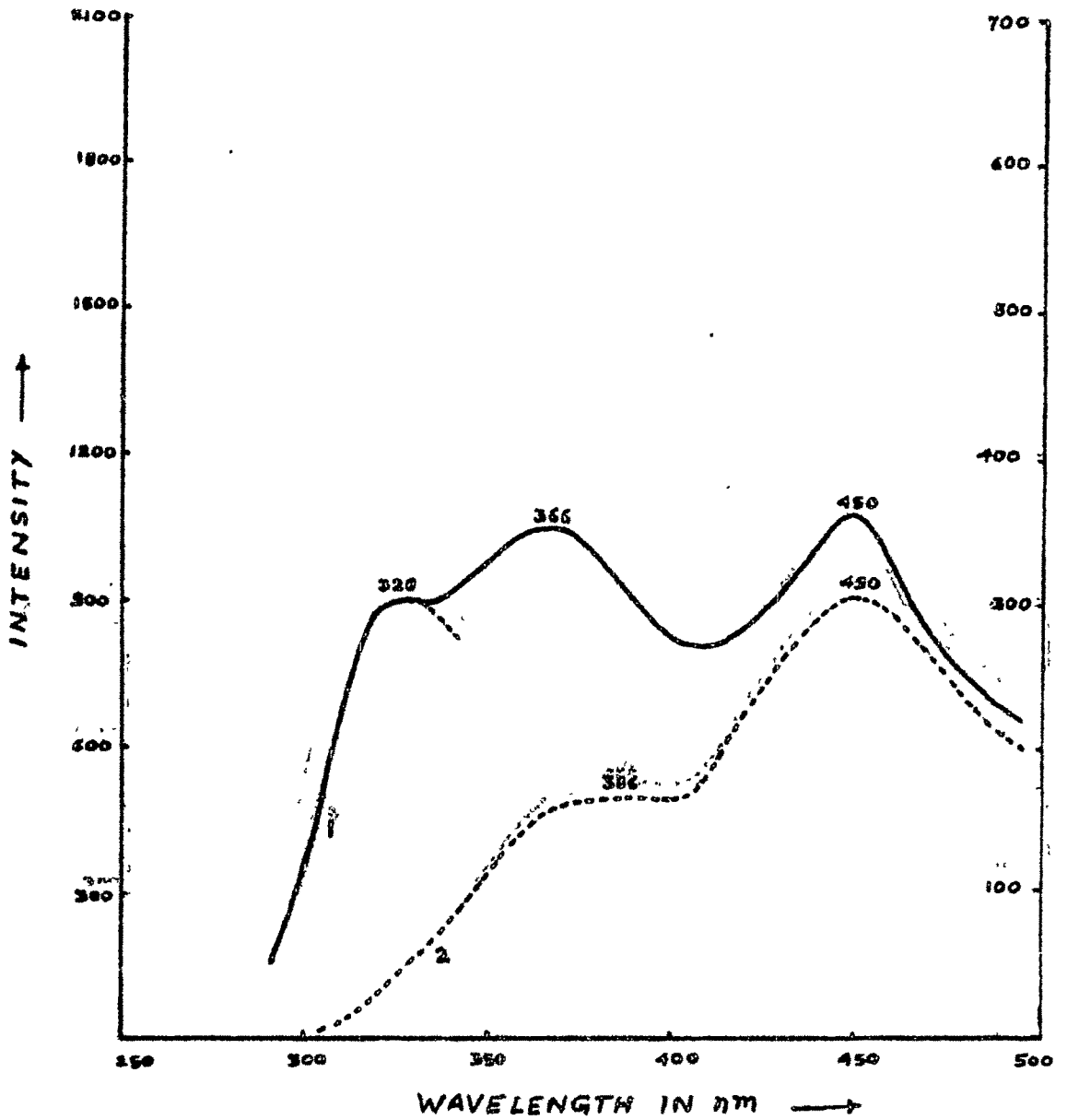

INTENSITY
WAVELENGTH IN nm
700
600
500
400
300
100
1800
1600
1200
800
600
300
250
300
350
400
450
500
328
366
450
450
386
1
2

FIG. 22

Fig. 23 : Excitation spectra of NaBr:Tl specimen for emission at 366 nm (Curve : 1) and at 370 nm (Curve : 2).

Specimens as-received by crystallization from aqueous solution and then compressed to tablet.

Tl concentration $\sim 10^{-1}$ m.f.

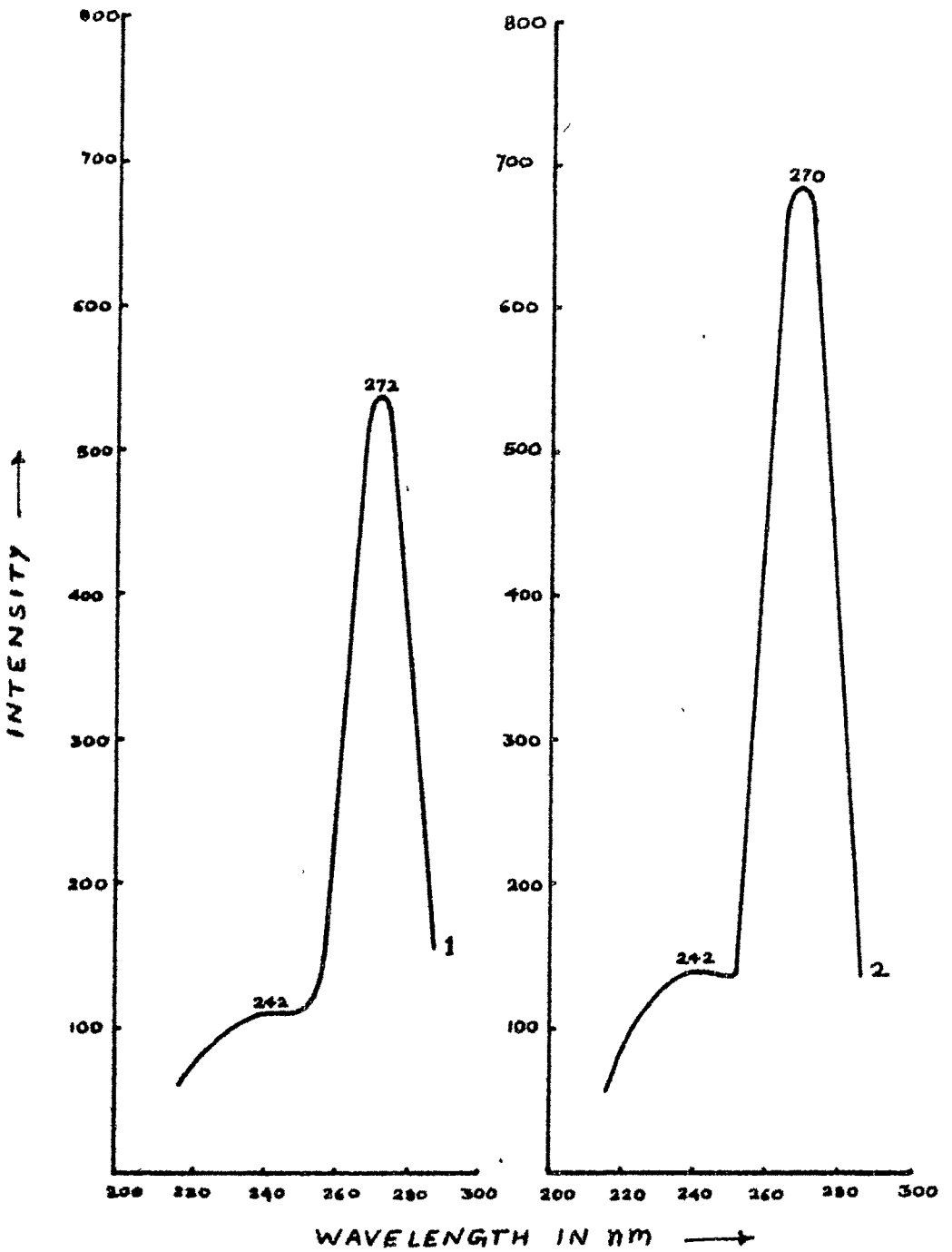

800
700
600
500
400
300
200
100
INTENSITY
272
242
1
800
700
600
500
400
300
200
100
270
242
2
200 220 240 260 280 300
200 220 240 260 280 300
WAVELENGTH IN nm

FIG. 23

Fig. 24 : Emission spectra of NaBr:Tl specimen upon excitation at 272 nm (Curve : 1) and at 242 nm (Curve : 2).

Specimens as-received by crystallization from aqueous solution and then compressed to tablet.

Tl concentration $\sim 10^{-1}$ m.f.

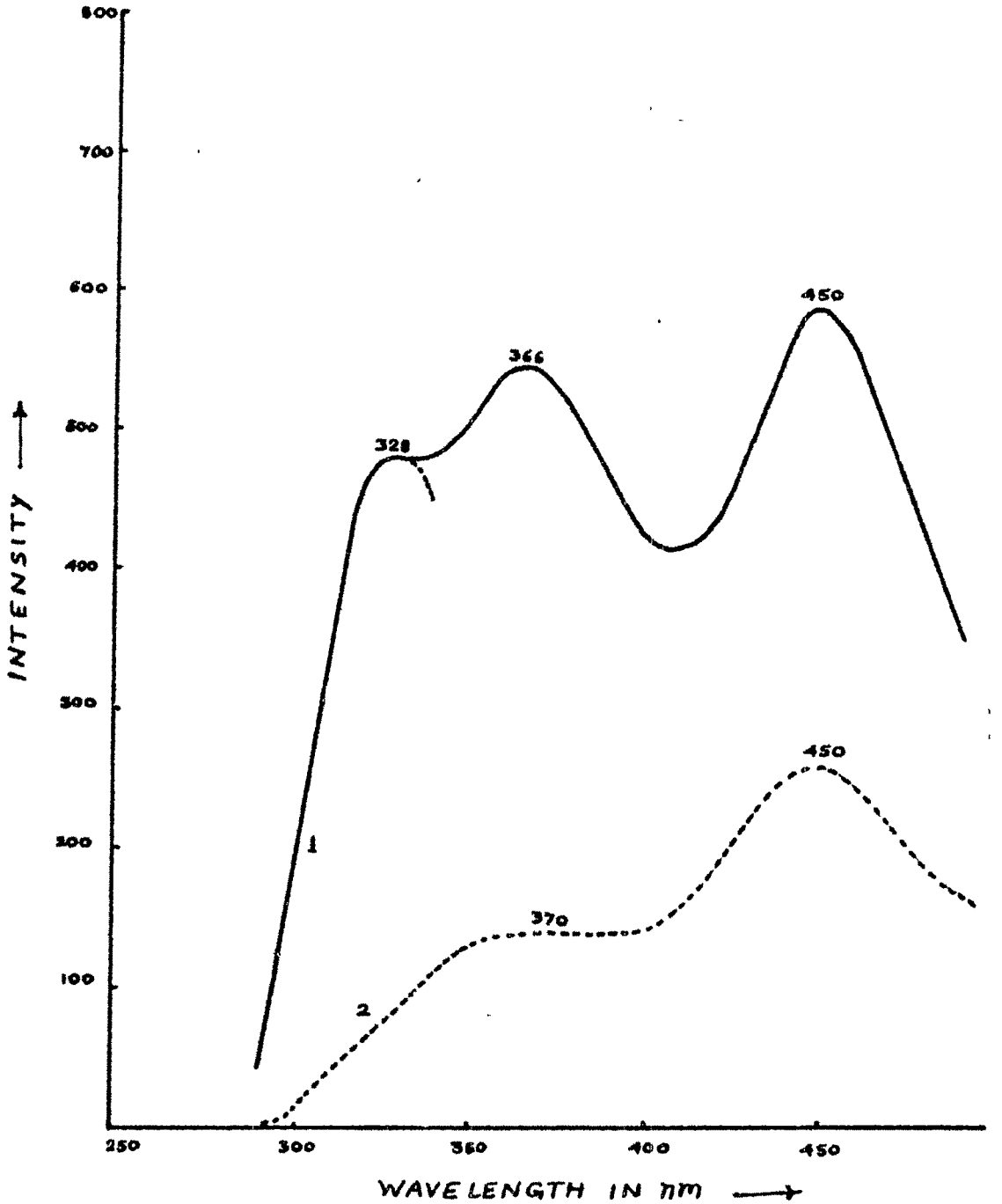

800
700
600
500
400
300
200
100
INTENSITY
328
366
450
1
2
370
450
250
300
350
400
450
WAVELENGTH IN nm

FIG. 24

Fig. 25 : Excitation spectra of NaBr:Tl powder specimens for emission at 390 nm (Curve : 1) and at 382 nm (Curve : 2).

Specimens annealed at 500°C for 4 hours in evacuated and sealed tube and quenched rapidly to room temperature.

Curve : 1 - Tl concentration $\sim 10^{-2}$ m.f.

Curve : 2 - Tl concentration $\sim 10^{-1}$ m.f.

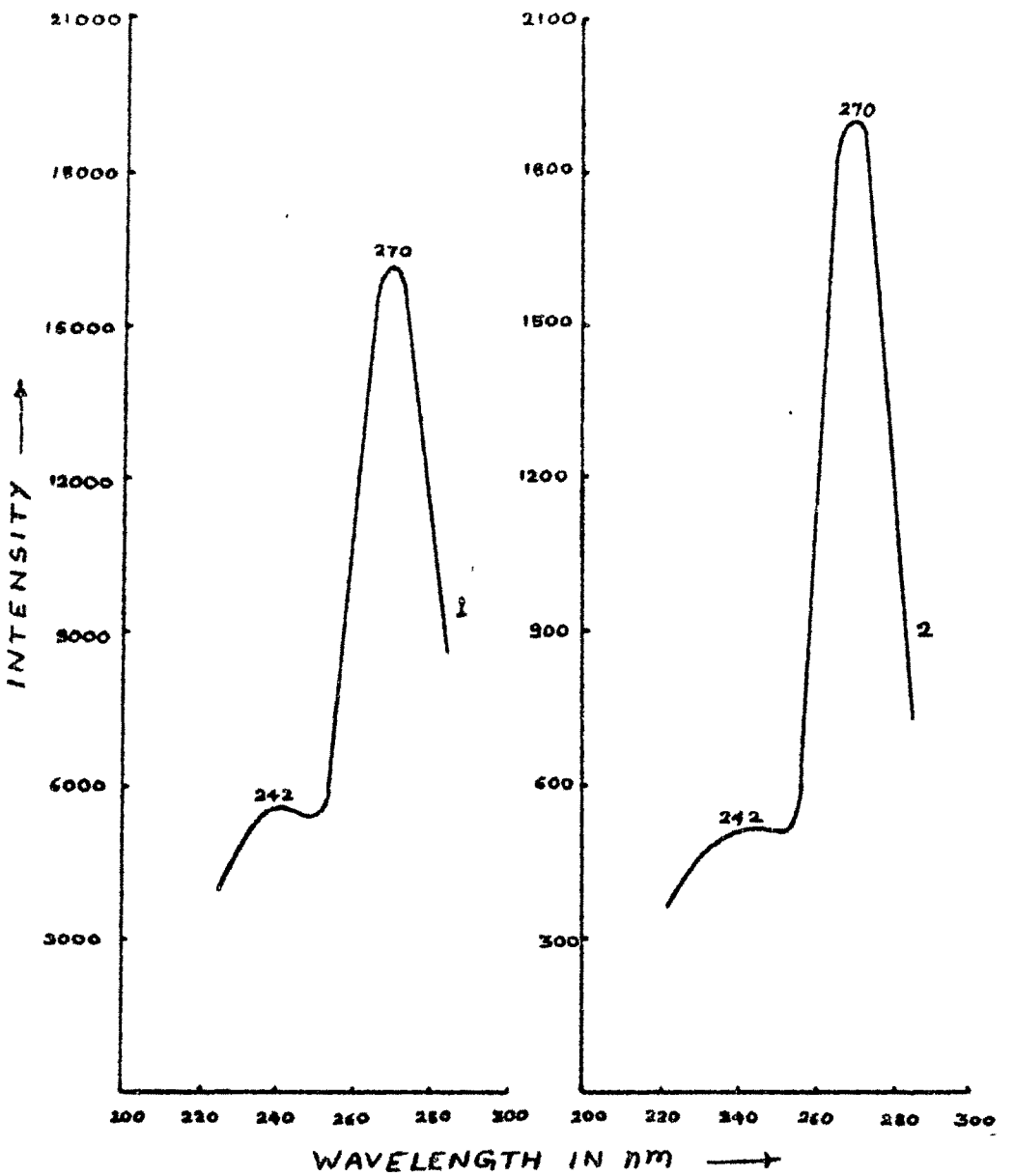

21000
18000
15000
12000
9000
6000
3000
INTENSITY
270
242
1
2100
1800
1500
1200
900
600
300
270
242
2
200
220
240
260
280
300
WAVELENGTH IN nm

FIG. 25

Fig. 26 : Emission spectra of NaBr:Tl powder specimens upon excitation at 270 nm.

Specimens annealed at 500°C for 4 hours in evacuated and sealed tube and quenched rapidly to room temperature.

Curve : 1 - Tl concentration $\sim 10^{-2}$ m.f.

Curve : 2 - Tl concentration $\sim 10^{-1}$ m.f.

Scale on the left hand side corresponds to Curve : 1

Scale on the right hand side corresponds to Curve : 2

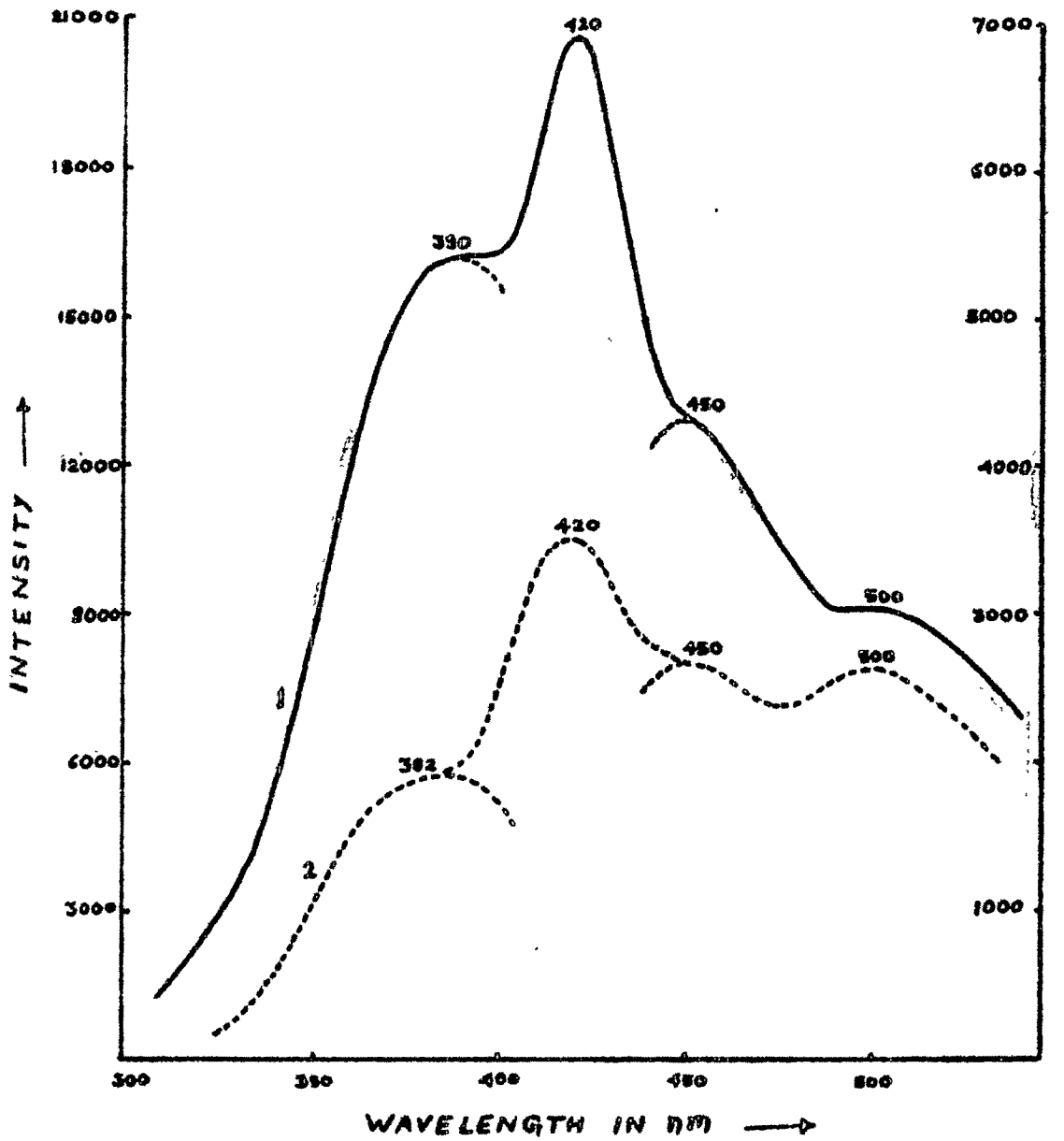

21000
18000
15000
12000
9000
6000
3000
7000
6000
5000
4000
3000
1000
INTENSITY
WAVELENGTH IN nm
300
350
400
450
500
420
390
450
500
420
450
500
382
1
2

FIG. 26

Fig. 27 : Excitation spectra of NaBr:Tl specimens for emission at 380 nm (Curve : 1) and at 386 nm (Curve : 2).

Specimens annealed at 500°C for 4 hours in evacuated and sealed tube, quenched rapidly to room temperature and subsequently compressed to tablet.

Curve : 1 - Tl concentration $\sim 10^{-2}$ m.f.

Curve : 2 - Tl concentration $\sim 10^{-1}$ m.f.

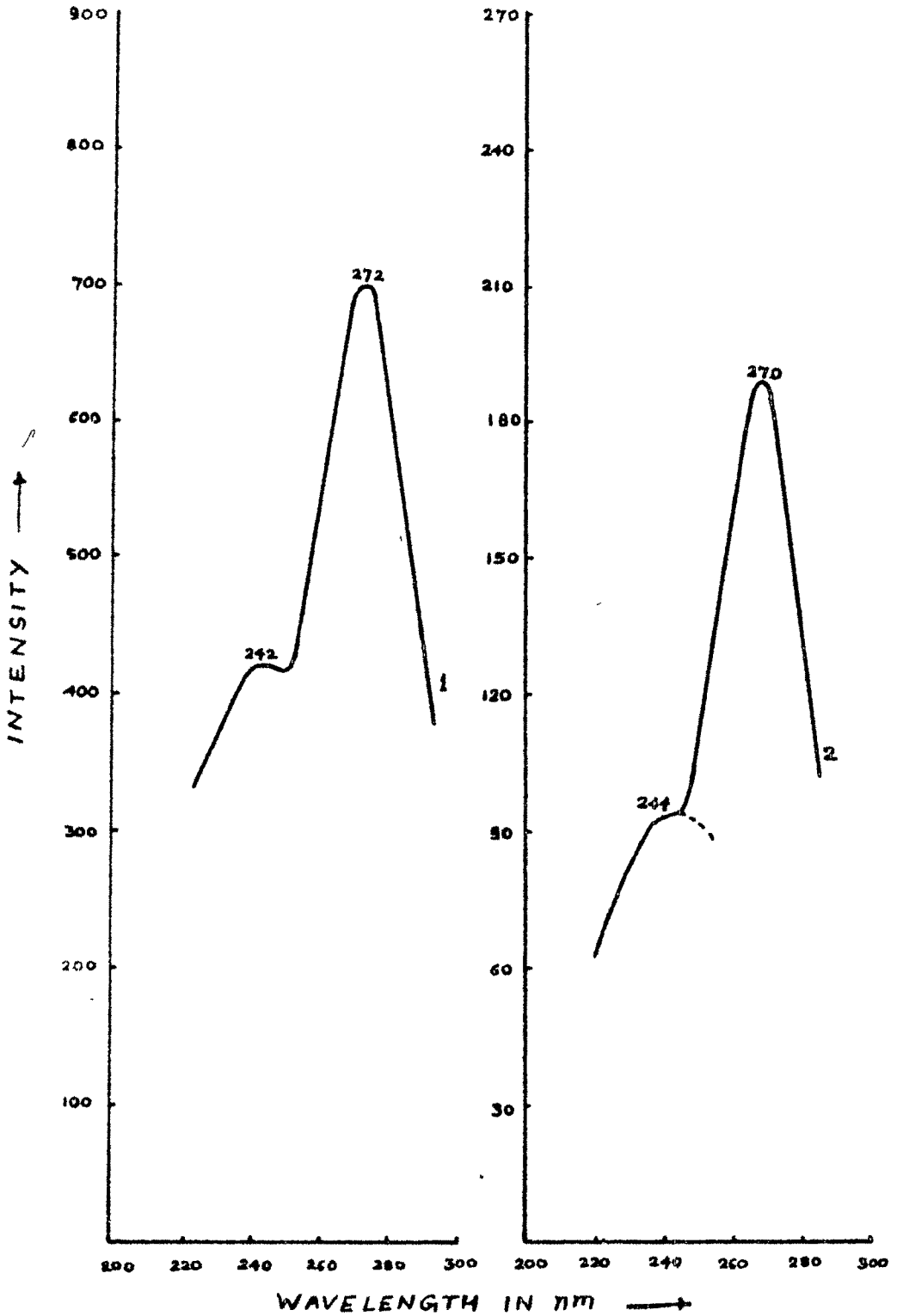

900
800
700
600
500
400
300
200
100
INTENSITY
272
242
1
270
240
210
180
150
120
90
60
30
270
244
2
200 220 240 260 280 300
200 220 240 260 280 300
WAVELENGTH IN nm

FIG. 27

Fig. 28 : Emission spectra of NaBr:Tl specimen upon excitation at 272 nm (Curve : 1) and at 270 nm (Curve : 2).

Specimens annealed at 500°C for 4 hours in evacuated and sealed tube, quenched rapidly to room temperature and subsequently compressed to tablet.

Curve : 1 - Tl concentration $\sim 10^{-2}$ m.f.

Curve : 2 - Tl concentration $\sim 10^{-1}$ m.f.

Scale on the left hand side corresponds to Curve : 1

Scale on the right hand side corresponds to Curve : 2

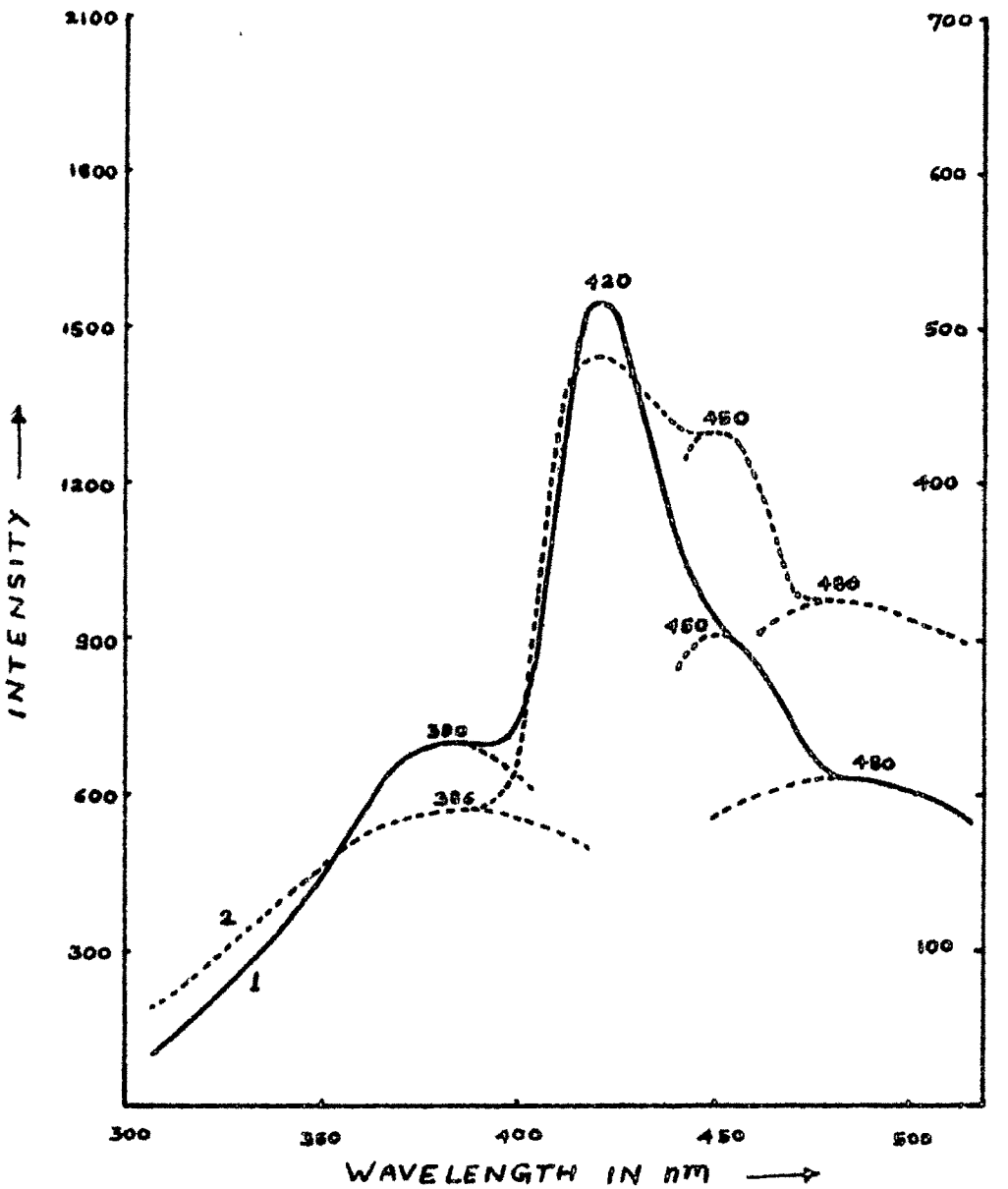

2100
1800
1500
1200
900
600
300
700
600
500
400
100
INTENSITY
420
450
480
460
380
386
480
2
1
300
350
400
450
500
WAVELENGTH IN nm

FIG. 28

Fig. 29 : Excitation spectra of NaBr:Tl powder specimen for emission at 388 nm.

Specimens annealed at 500°C for 4 hours in evacuated and sealed tube and slowly cooled to room temperature.

Curve : 1 - Tl concentration $\backsim 10^{-2}$ m.f.

Curve : 2 - Tl concentration $\sim 10^{-1}$ m.f.

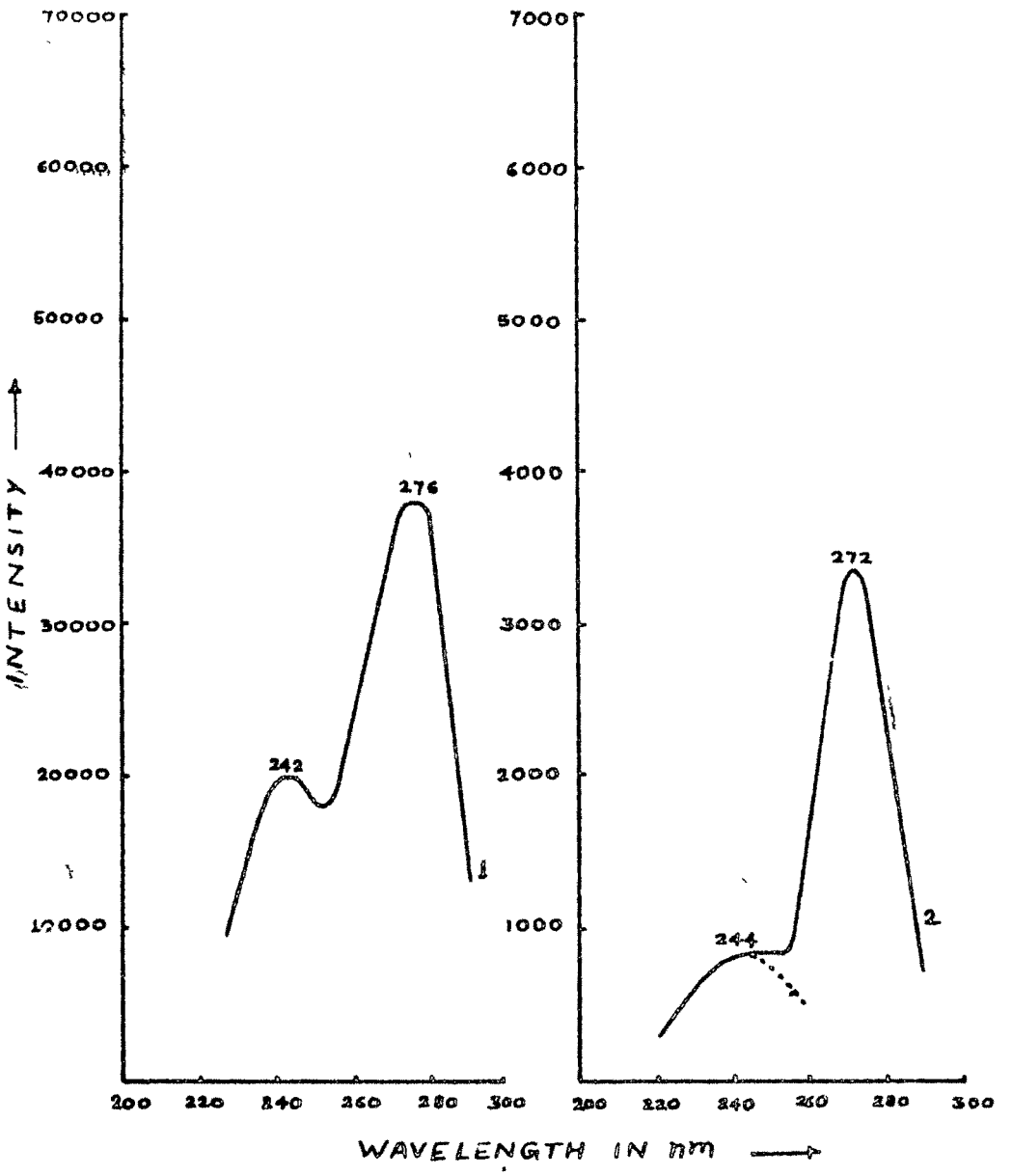

70000
60000
50000
40000
30000
20000
10000
7000
6000
5000
4000
3000
2000
1000
INTENSITY
242
276
272
244
1
2
200
220
240
260
280
300
WAVELENGTH IN nm

FIG. 29

Fig. 30 : Emission spectra of NaBr:Tl powder specimens upon excitation at 278 nm (Curve : 1) and at 272 nm (Curve : 2).

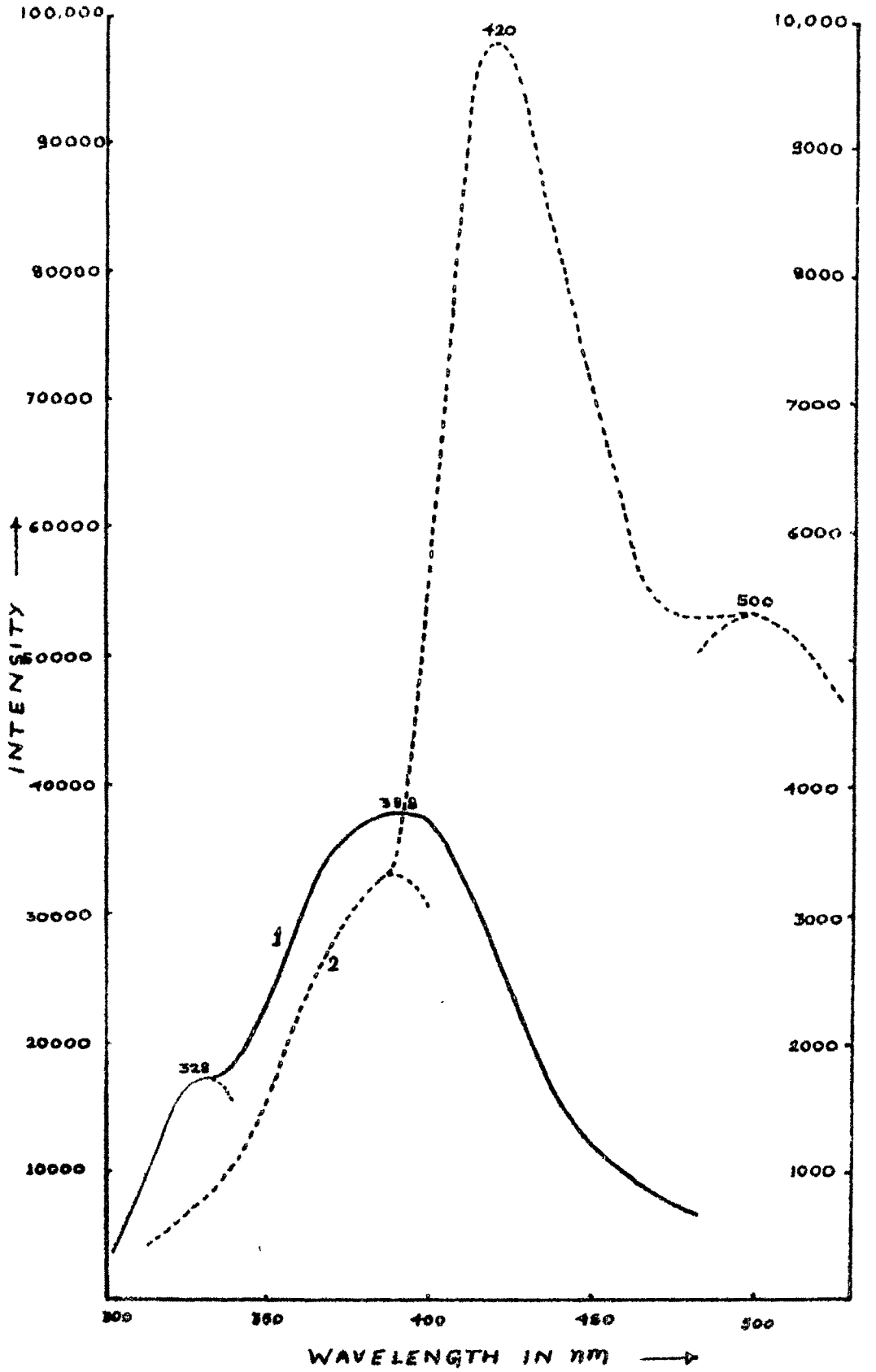
Specimens annealed at 500°C for 4 hours in evacuated and sealed tube and slowly cooled to room temperature.

Curve : 1 - Tl concentration $\sim 10^{-2}$ m.f.

Curve : 2 - Tl concentration $\sim 10^{-1}$ m.f.

Scale on the left hand side corresponds to Curve : 1

Scale on the right hand side corresponds to Curve : 2


100,000
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60000
50000
40000
30000
20000
10000
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
INTENSITY
420
500
328
1
2
300
350
400
450
500
WAVELENGTH IN nm

FIG. 30

Fig. 31 : Excitation spectra of NaBr : Tl specimens for emission at 380 nm (Curve : 1) and at 382 nm (Curve : 2).

Specimens annealed at 500°C for 4 hours in evacuated and sealed tube, slowly cooled to room temperature and subsequently compressed to tablet.

Curve : 1 - Tl concentration $\sim 10^{-2}$ m.f.

Curve : 2 - Tl concentration $\sim 10^{-1}$ m.f.

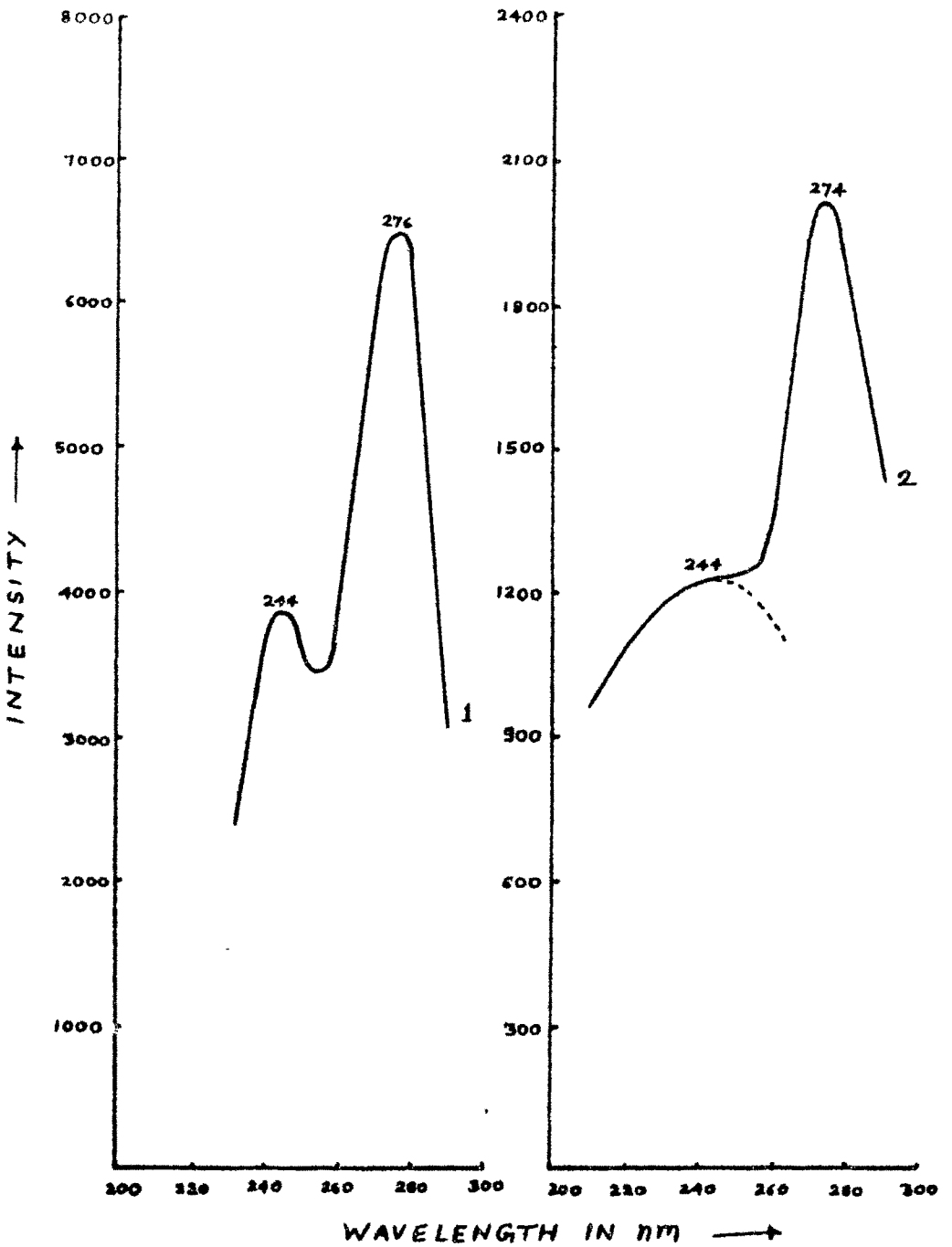
8000
7000
6000
5000
4000
3000
2000
1000
INTENSITY
276
244
1
2400
2100
1800
1500
1200
900
600
300
274
244
2
200
220
240
260
280
300
WAVELENGTH IN nm

FIG. 31

Fig. 32 : Emission spectra of NaBr:Tl specimens upon excitation at 276 nm (Curve : 1) and at 274 nm (Curve : 2).

Specimens annealed at 500°C for 4 hours in evacuated and sealed tube, slowly cooled to room temperature and subsequently compressed to tablet.

Curve : 1 - Tl concentration $\sim 10^{-2}$ m.f.

Curve : 2 - Tl concentration $\sim 10^{-1}$ m.f.

Scale on the left hand side corresponds to Curve : 1

Scale on the right hand side corresponds to Curve : 2

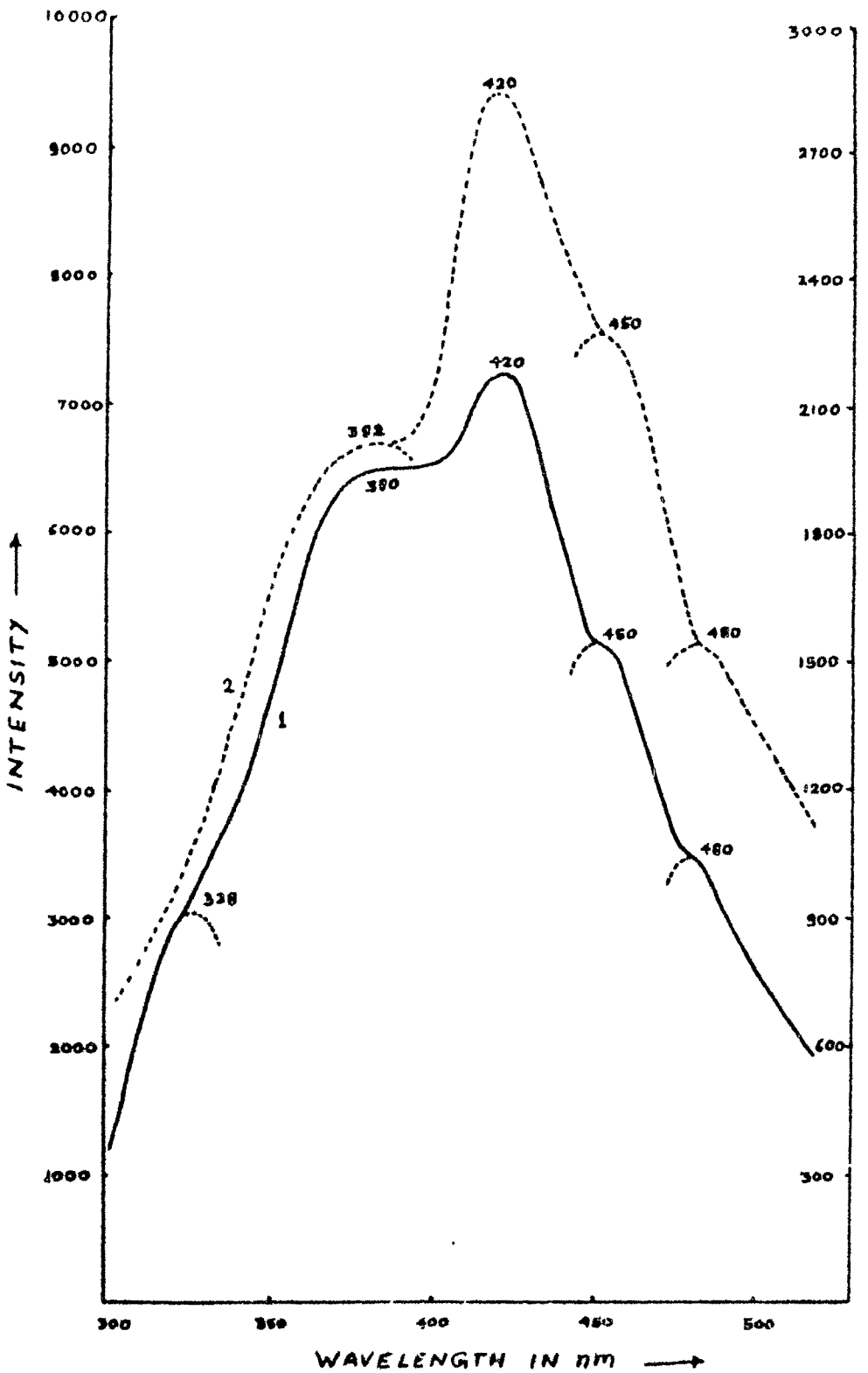
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
3000
2700
2400
2100
1800
1500
1200
900
600
300
INTENSITY
420
450
420
392
390
460
480
480
338
2
1
300
350
400
450
500
WAVELENGTH IN nm

FIG. 32

Fig. 33 : Excitation spectra of NaBr:Tl powder specimens for emission at 420 nm

Curve : 1 - Specimen as-received by crystallization from aqueous solution.
Tl concentration $\sim 10^{-1}$ m.f.

Curve : 2 - Specimen annealed at 500°C for 4 hours in evacuated and sealed tube and quenched rapidly to room temperature.
Tl concentration $\sim 10^{-1}$ m.f.

Curve : 3 - Specimen annealed at 500°C for 4 hours in evacuated and sealed tube and slowly cooled to room temperature.
Tl concentration $\sim 10^{-1}$ m.f.

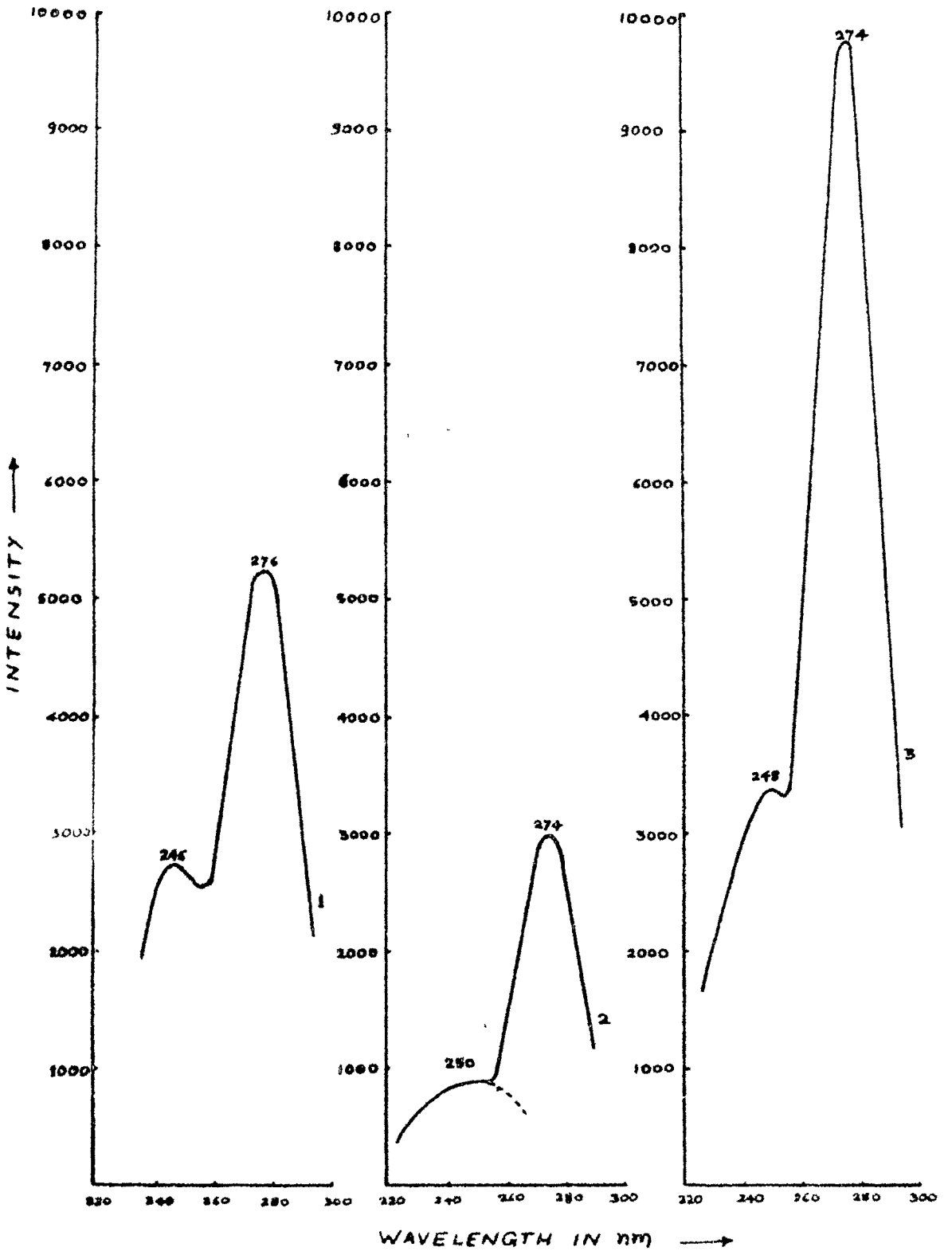
INTENSITY
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
246
276
1
250
274
2
248
274
3
220
240
260
280
300
WAVELENGTH IN nm

FIG. 33

Fig. 34 : Excitation spectra of NaBr:Tl specimens for emission at 450 nm (Curves : 1a, 2a and 3a) and at 480 nm (Curves : 2b and 3b).

Curve : 1 - Specimen as-received by crystallization from aqueous solution and then compressed to tablet.
Tl concentration $\sim 10^{-1}$ m.f.

Curve : 2 - Specimen annealed at 500°C for 4 hours in evacuated and sealed tube, quenched rapidly to room temperature and subsequently compressed to tablet.
Tl concentration $\sim 10^{-1}$ m.f.

Curve : 3 - Specimen annealed at 500°C for 4 hours in evacuated and sealed tube, slowly cooled to room temperature and subsequently compressed to tablet.
Tl concentration $\sim 10^{-1}$ m.f.

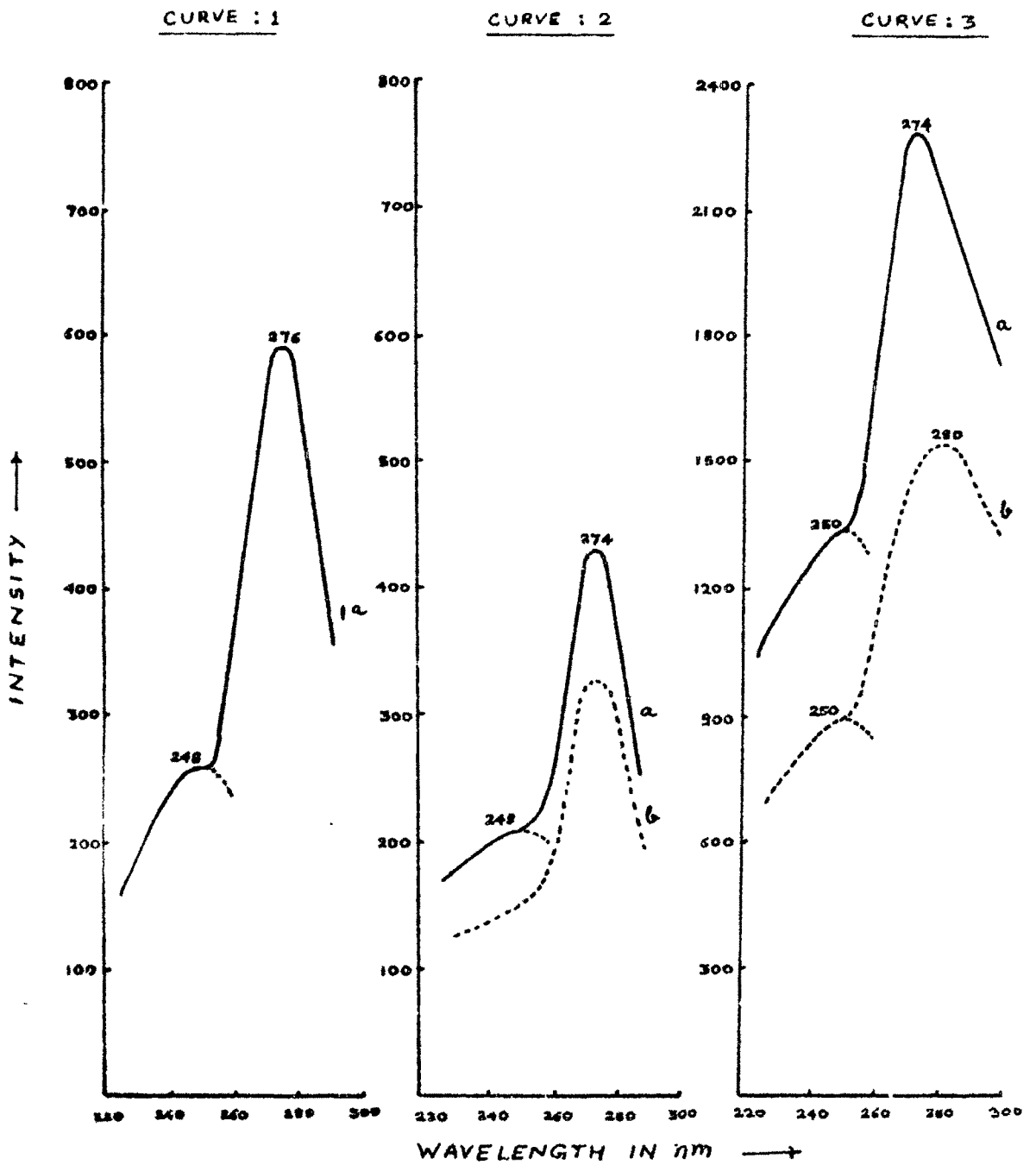
CURVE : 1
CURVE : 2
CURVE : 3
INTENSITY
WAVELENGTH IN nm
276
248
274
250
a
b

FIG. 34

Fig. 35 : Excitation spectrum of NaBr:Tl powder specimen for emission at 500 nm.

Specimen annealed at 500°C for 4 hours in evacuated and sealed tube and slowly cooled to room temperature.

Tl concentration $\sim 10^{-1}$ m.f.

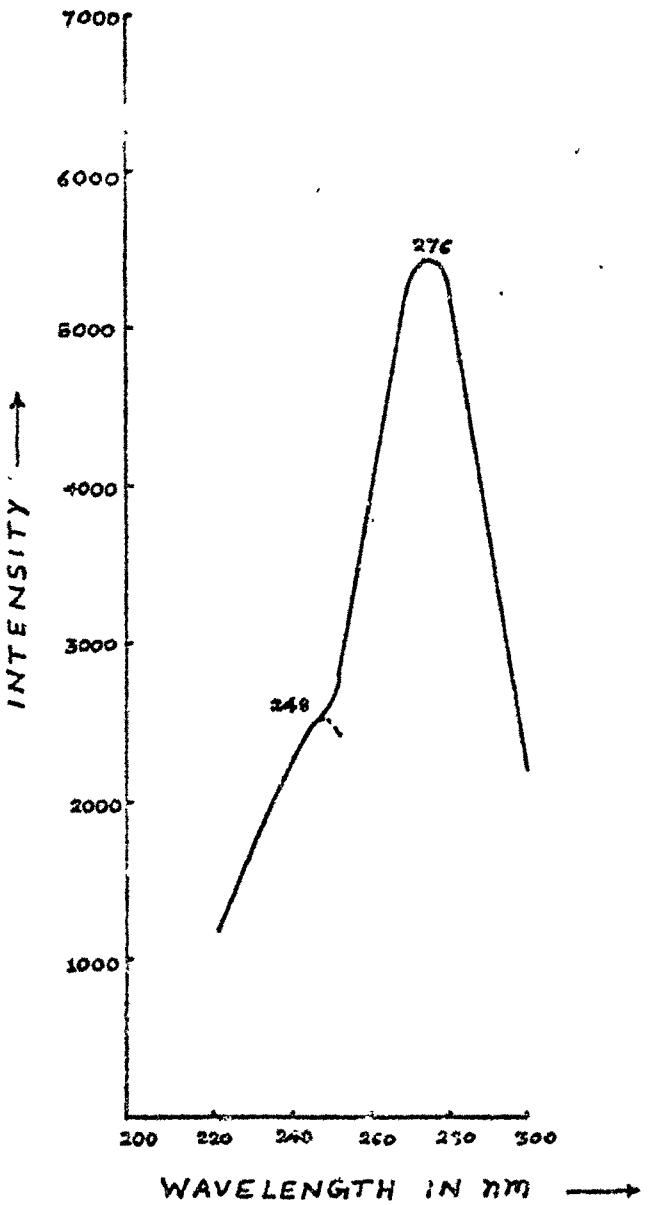
7000
6000
5000
4000
3000
2000
1000
INTENSITY
276
248
200
220
240
260
280
300
WAVELENGTH IN nm

FIG. 35

Fig. 36 : Excitation spectra of TlBr specimens

Curve : 1 - Excitation spectrum of TlBr - powder for emission at 360 nm.

Curve : 2 - Excitation spectrum of TlBr - powder compressed to tablet for emission at 360 nm.

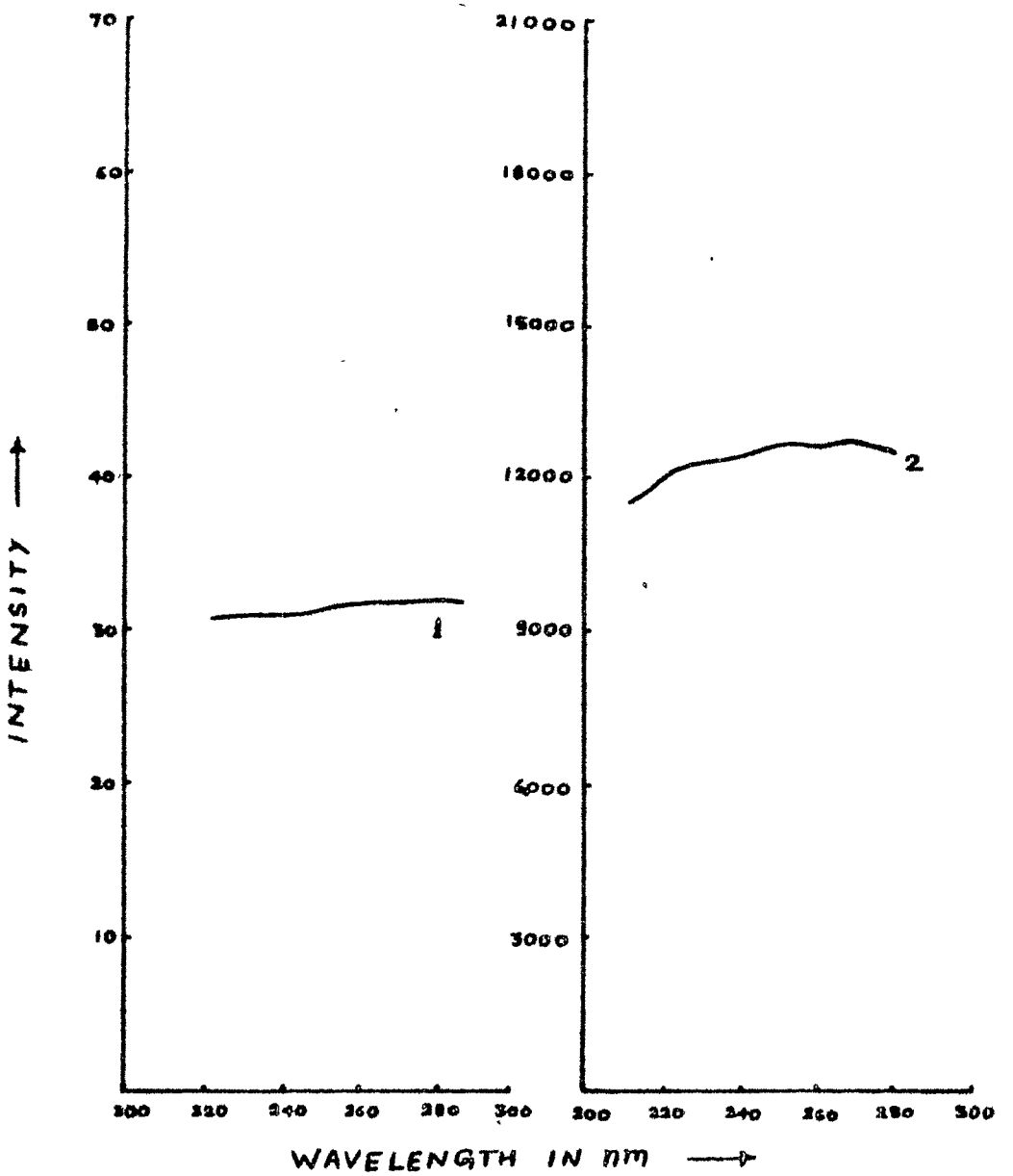
70
60
50
40
30
20
10
INTENSITY
21000
18000
15000
12000
9000
6000
3000
1
2
200
220
240
260
280
300
WAVELENGTH IN nm

FIG. 36

Fig. 37 : Emission spectra of TlBr specimens

Curve : 1 - Emission spectrum of TlBr powder upon excitation at 270 nm.

Curve : 2 - Emission spectrum of TlBr powder compressed to tablet upon excitation at 270 nm.

Scale on the left hand side corresponds to Curve : 1

Scale on the right hand side corresponds to Curve : 2

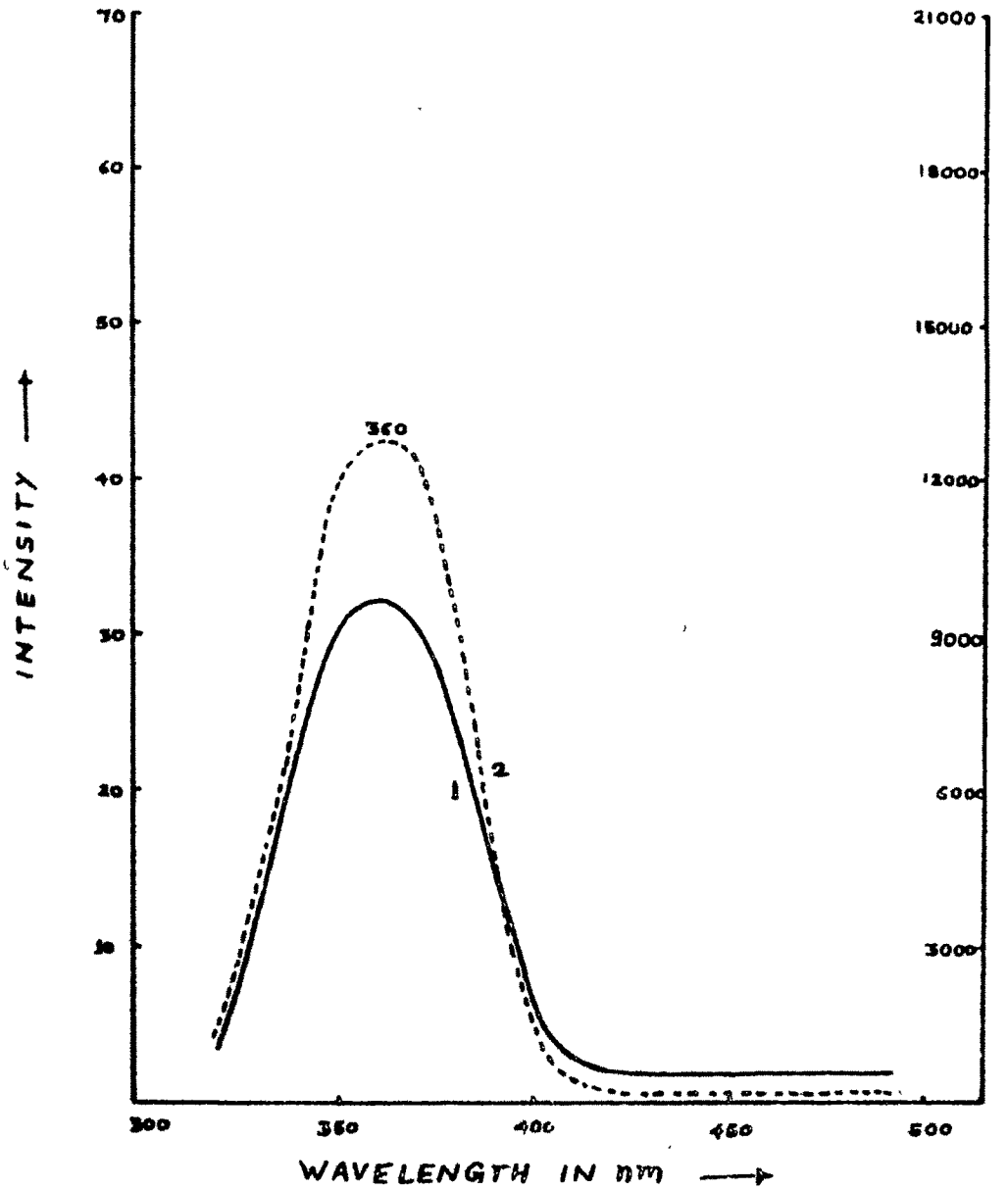
70
60
50
40
30
20
10
21000
18000
15000
12000
9000
6000
3000
INTENSITY
360
1
2
300
350
400
450
500
WAVELENGTH IN nm

FIG. 37

Fig. 38 : Excitation of aqueous TlBr-solution as a function of TlBr concentration.

Curve : 1 - Saturated TlBr-solution

Curve : 2 - Dilution of saturated TlBr-solution with water in the proportion of .....1 : 1

Curve : 3 - " " .....1 : 2

Curve : 4 - " " .....1 : 3

Curve : 5 - " " .....1 : 5

Curve : 6 - " " .....1 : 7

Curve : 7 - " " .....1 : 10

Curve : 8 - " " .....1 : 50

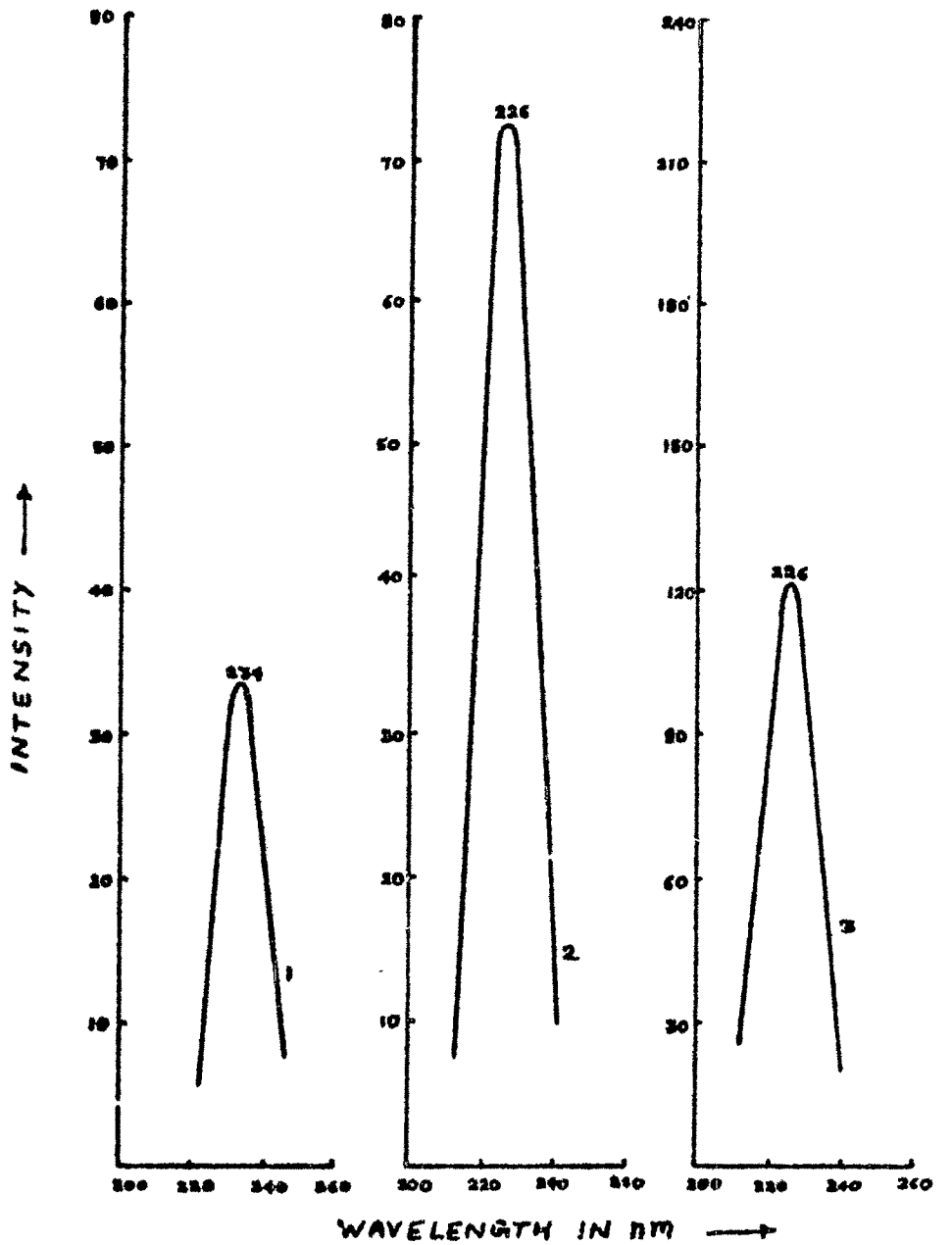

FIG. 38

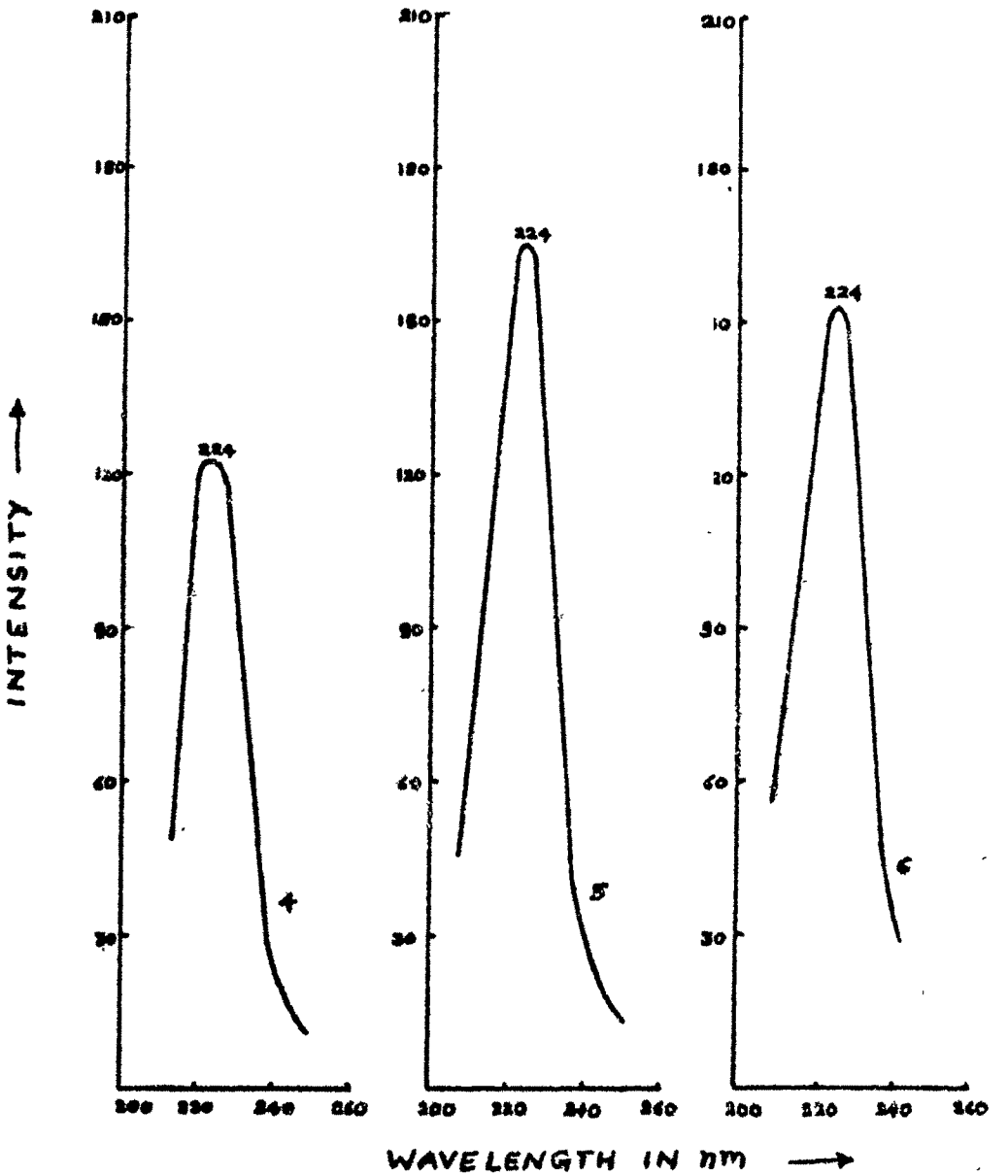

FIG. 38

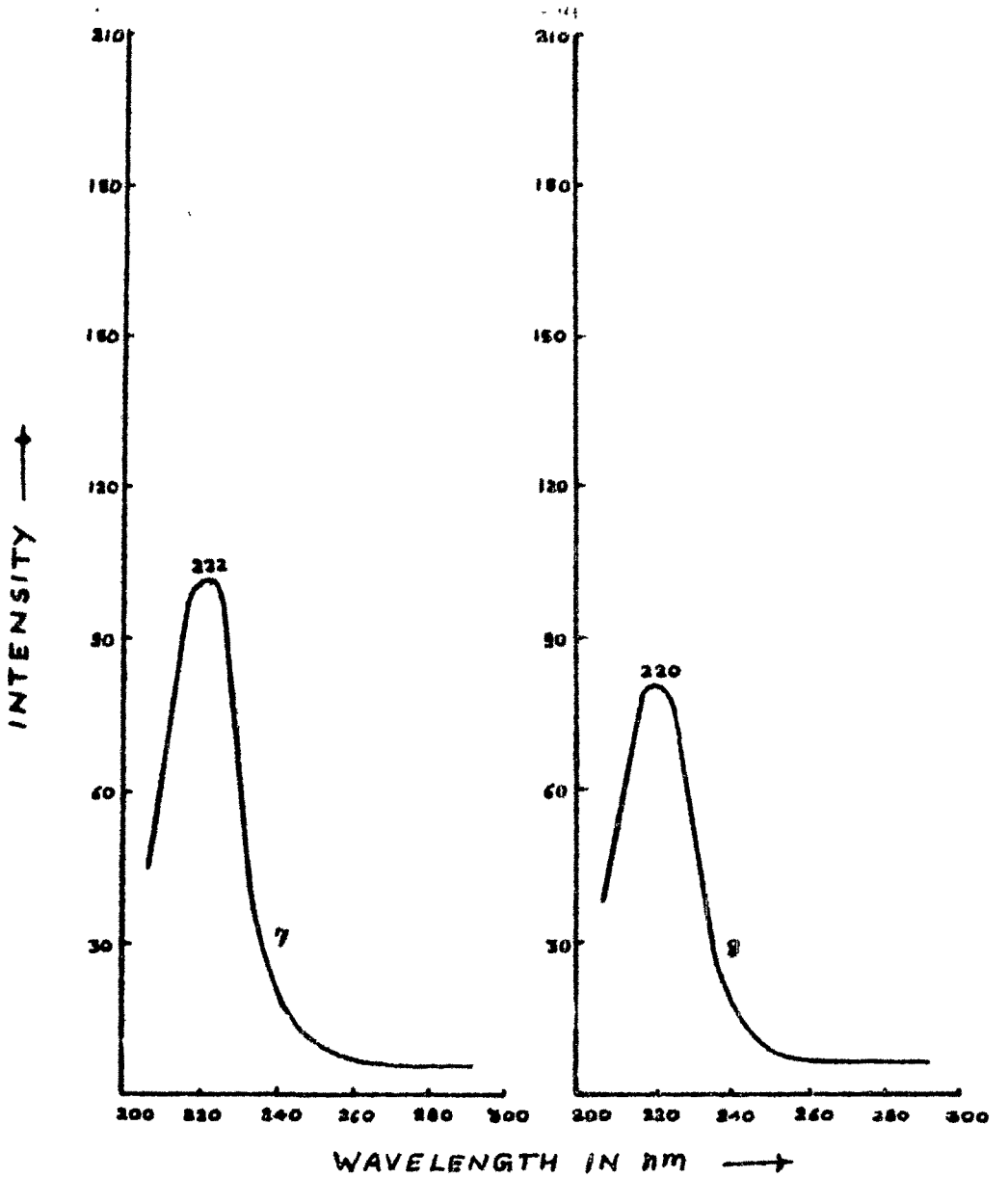
INTENSITY
210
180
150
120
90
60
30
222
7
220
8
200
220
240
260
280
300
WAVELENGTH IN nm

FIG. 38

Fig. 39 : Fluorescence intensity of aqueous TlBr-solution as a function of TlBr concentration.

Curve : 1 - Saturated TlBr-solution

Curve : 2 - Dilution of the saturated TlBr-solution with water in the proportion of ..... 1 : 1

Curve : 3 - " " ..... 1 : 2

Curve : 4 - " " ..... 1 : 3

Curve : 5 - " " ..... 1 : 5

Curve : 6 - " " ..... 1 : 7

Curve : 7 - " " ..... 1 : 10

Curve : 8 - " " ..... 1 : 50

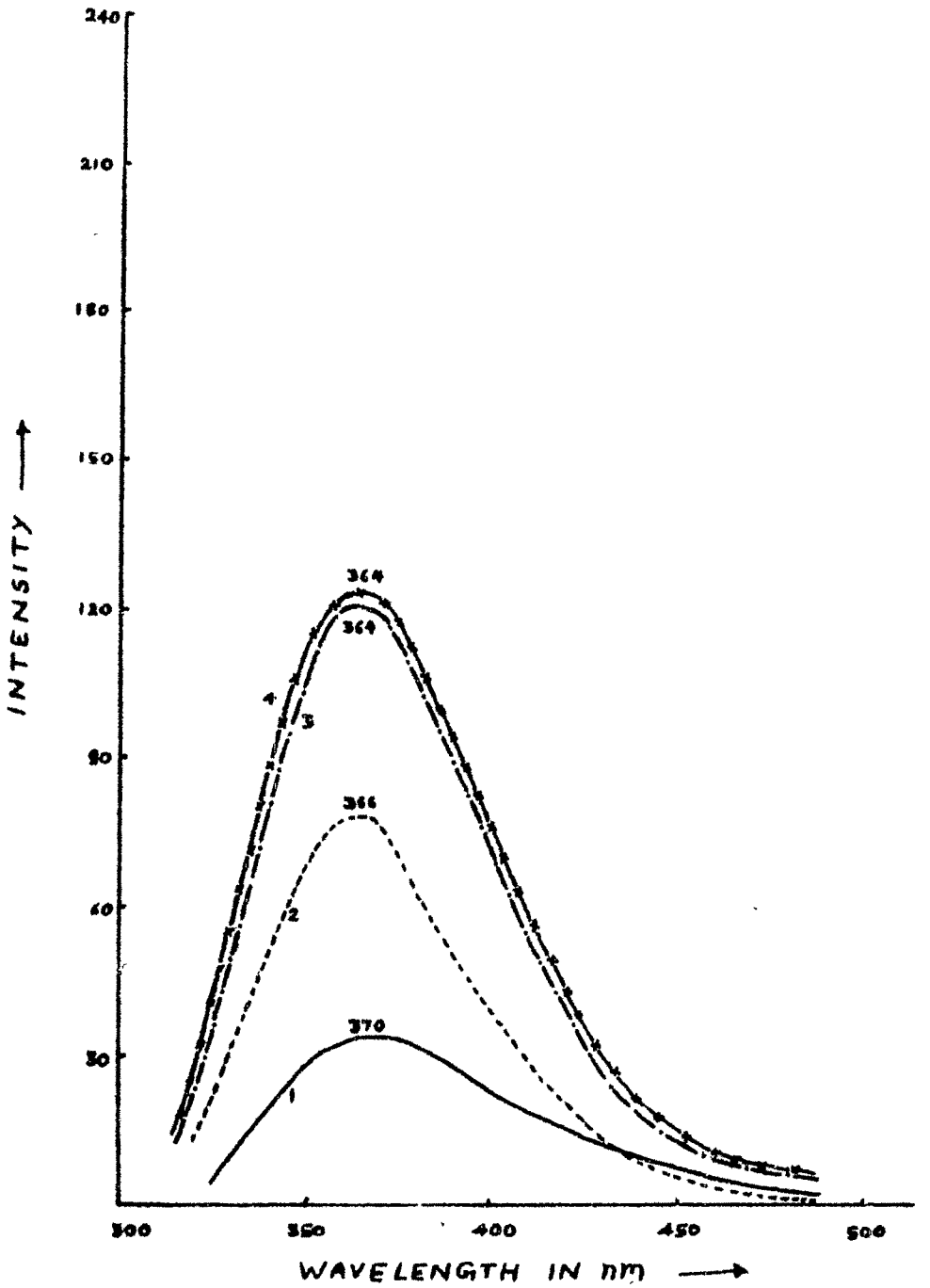
240
210
180
150
120
90
60
30
INTENSITY
364
364
366
370
4
3
2
1
300
350
400
450
500
WAVELENGTH IN nm

FIG. 39

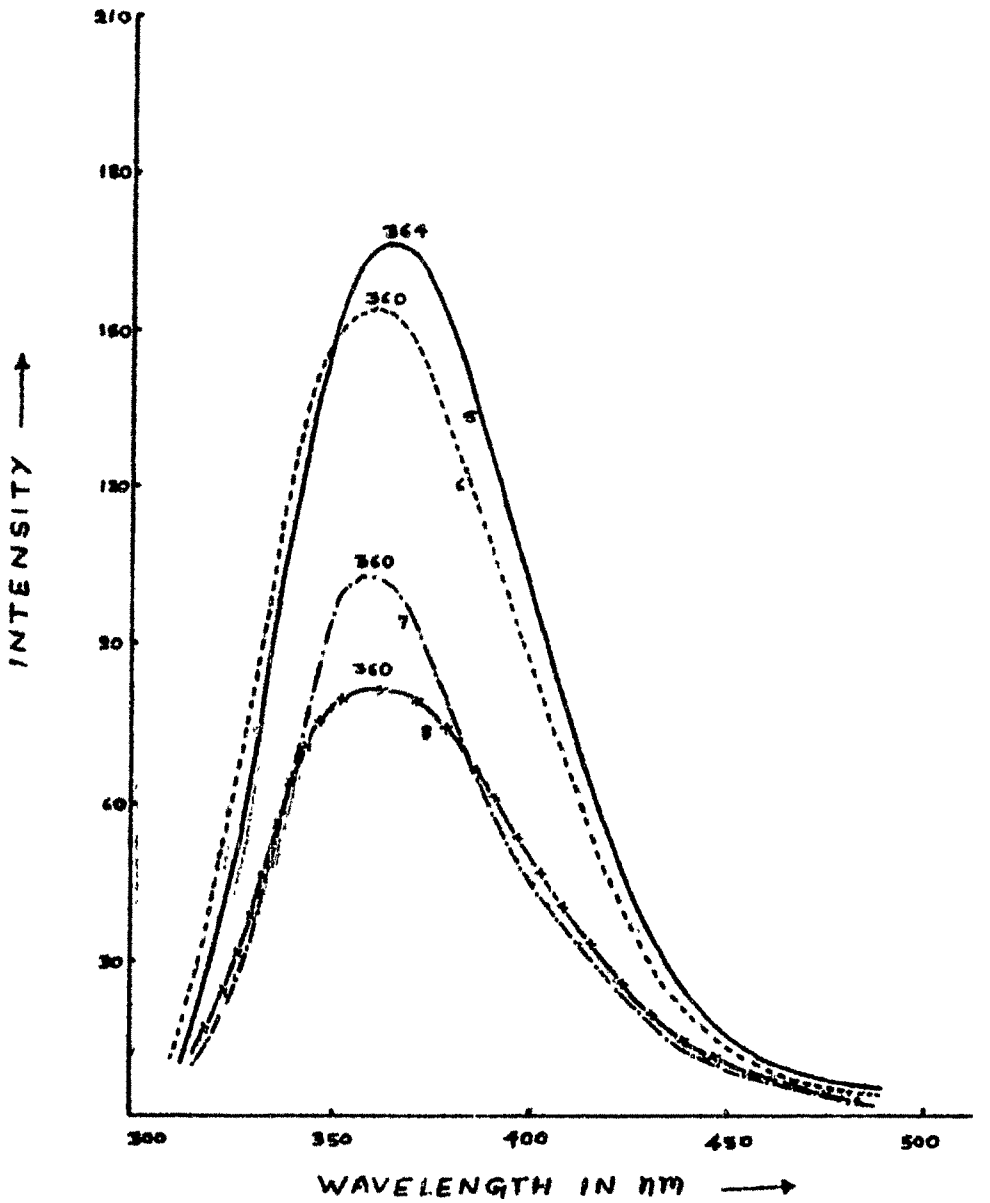
210
180
150
120
90
60
30
364
360
360
360
INTENSITY
300
350
400
450
500
WAVELENGTH IN nm

FIG. 39

Fig. 40 : Excitation spectra of aqueous saturated NaBr-solution with varying concentrations of TlBr for emission at 460 nm.

Curve : 1 - 1 drop of saturated TlBr-solution in 1c.c. of saturated NaBr-solution.

Curve : 2 - 2 drops " " "

Curve : 3 - 3 drops " " "

Curve : 4 - 5 drops " " "

Curve : 5 - 6 drops " " "

Curve : 6 - 7 drops " " "

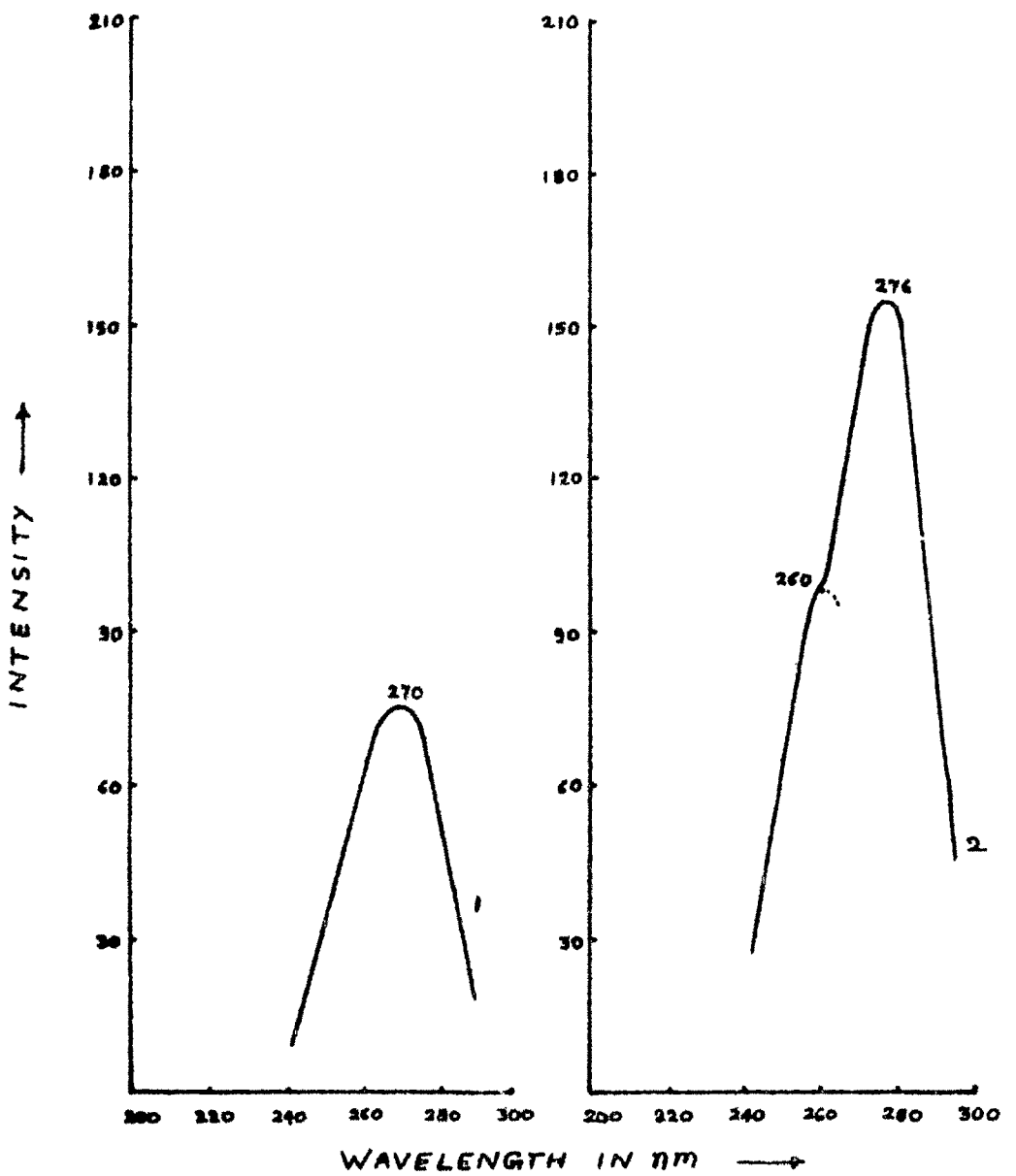
210
180
150
120
90
60
30
INTENSITY
270
1
276
260
2
200
220
240
260
280
300
WAVELENGTH IN nm

FIG. 40

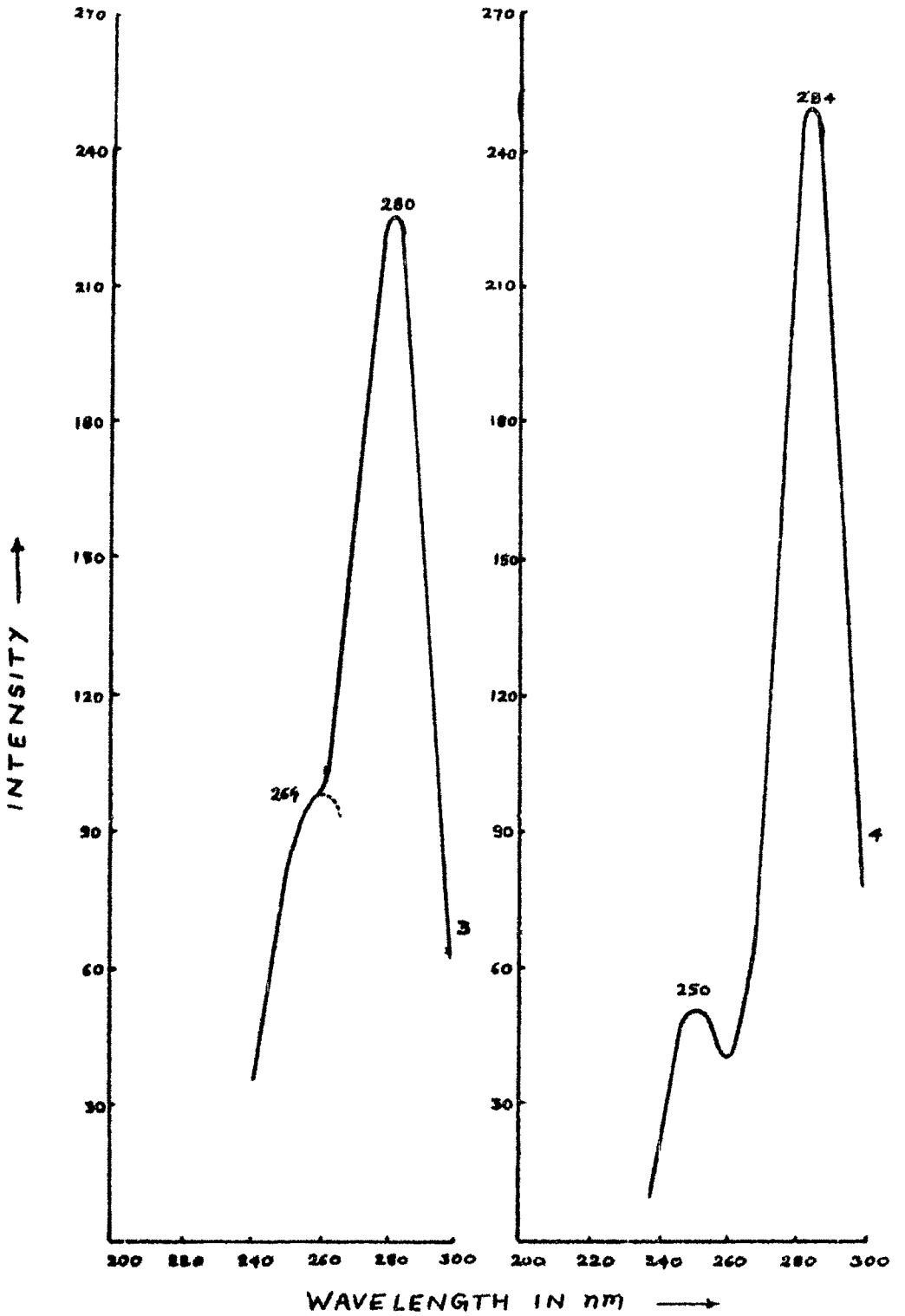
270
240
210
180
150
120
90
60
30
INTENSITY
280
264
3
284
250
4
200
220
240
260
280
300
WAVELENGTH IN nm

FIG. 10

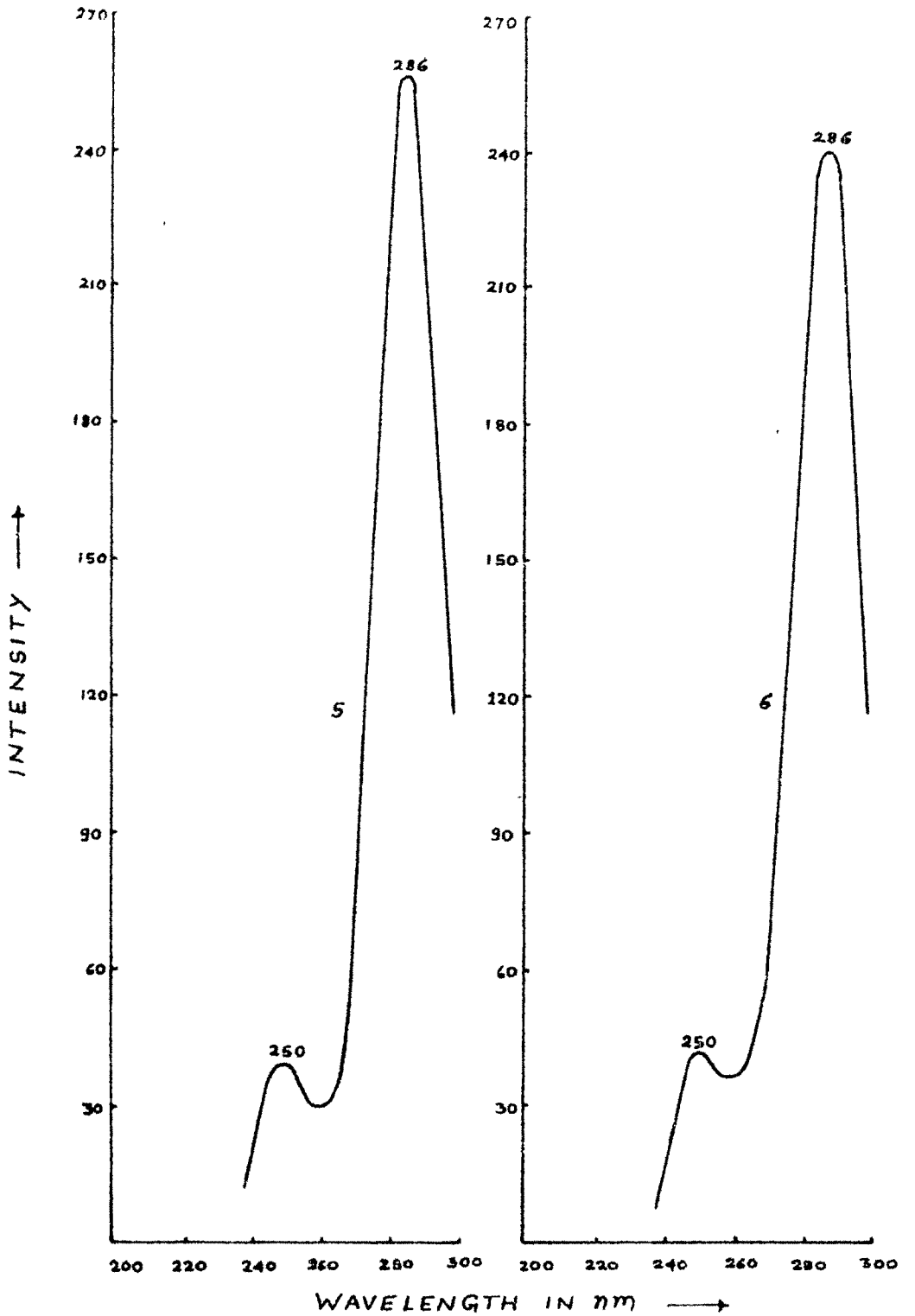
INTENSITY
270
240
210
180
150
120
90
60
30
286
250
5
6
200
220
240
260
280
300
WAVELENGTH IN nm

FIG. 40

Fig. 41 : Emission spectra of saturated NaBr-solution with varying quantities of TlBr upon excitation at appropriate wavelengths (corresponding to principle band) as observed from Curve in Fig. 40

Curve : 1 - 1 drop of saturated TlBr-solution in 1 c.c. of saturated NaBr--solution; Excitation at ... 270 nm

Curve : 2 - 2 drops " " " ... 276 nm

Curve : 3 - 3 drops " " " ... 280 nm

Curve : 4 - 5 drops " " " ... 284 nm

Curve : 5 - 6 drops " " " ... 286 nm

Curve : 6 - 7 drops " " " ... 286 nm

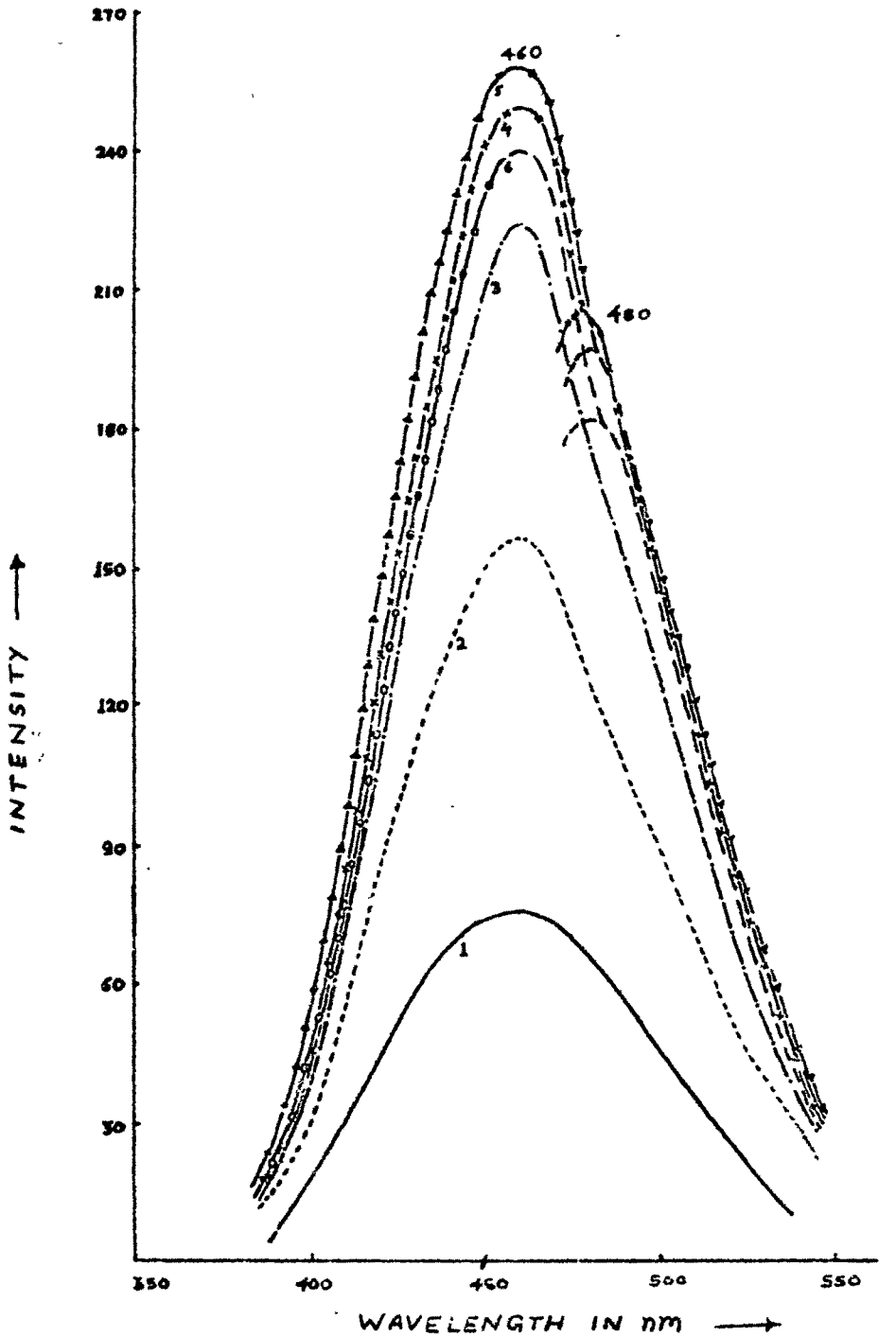
270
240
210
180
150
120
90
60
30
INTENSITY
460
480
1
2
3
4
5
6
350
400
450
500
550
WAVELENGTH IN nm

FIG. 41

Fig. 42 : Excitation spectra of TlBr:Na specimens

Curve : 1 - Excitation spectra of NaBr doped TlBr (TlBr:Na) for emission at (a) 360 nm, (b) 460 nm and (c) 500 nm. Na concentration $\sim$ 0.3 m.f.

Curve : 2 - Excitation spectra of NaBr doped TlBr (TlBr:Na) for emission at (a) 370 nm, (b) 460 nm and (c) 500 nm. Na concentration $\sim$ 0.5 m.f.

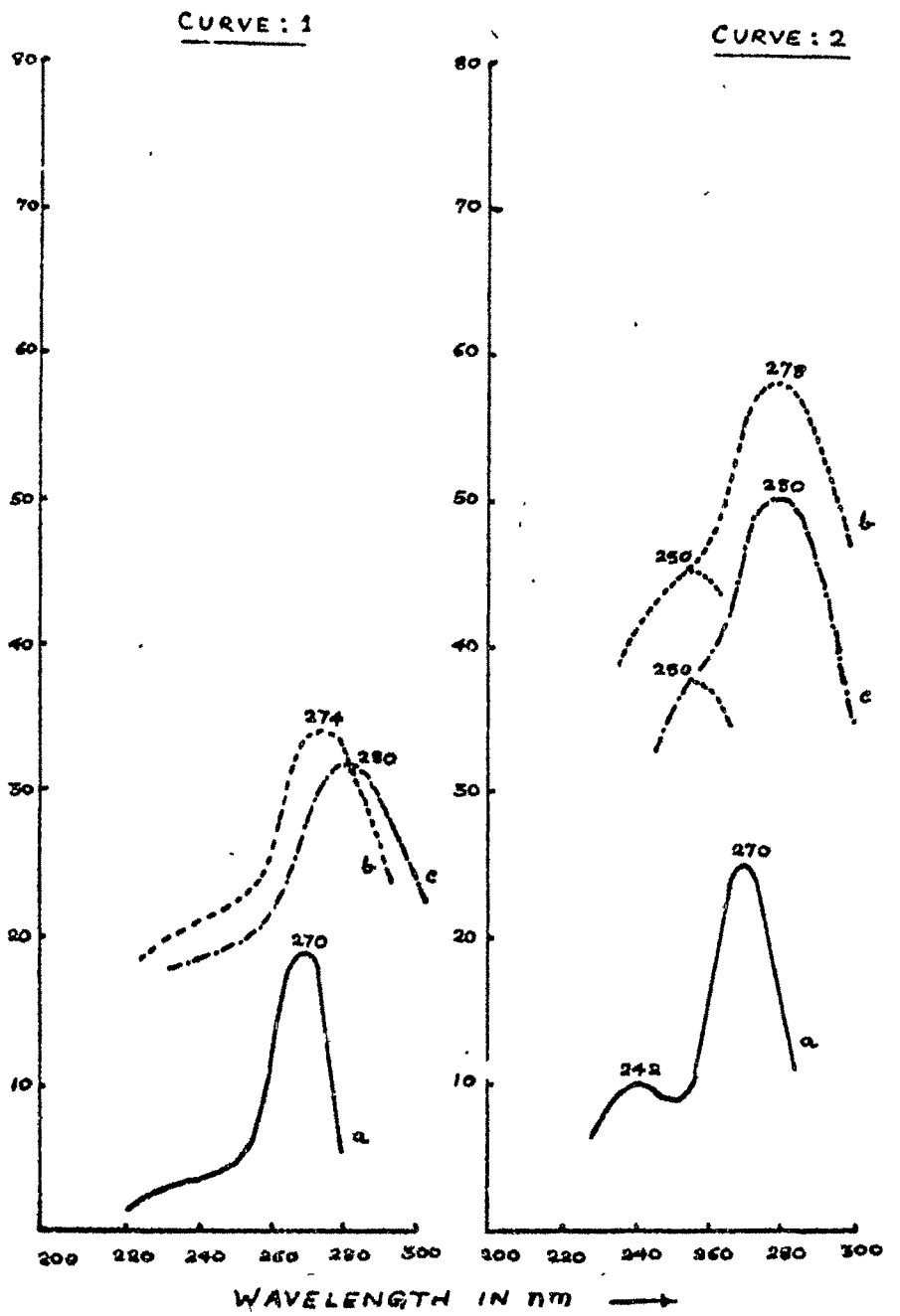
CURVE : 1
CURVE : 2
90
70
60
50
40
30
20
10
274
280
270
a
b
c
278
250
250
270
242
200
220
240
260
280
300
WAVELENGTH IN nm

FIG. 42

Fig. 43 : Emission spectra of TlBr:Na specimens upon excitation at 280 nm .

Curve : 1 - Na concentration $\sim$ 0.3 m.f.

Curve : 2 - Na concentration $\sim$ 0.5 m.f.

Scale on the left hand side corresponds to Curve : 1

Scale on the right hand side corresponds to Curve : 2

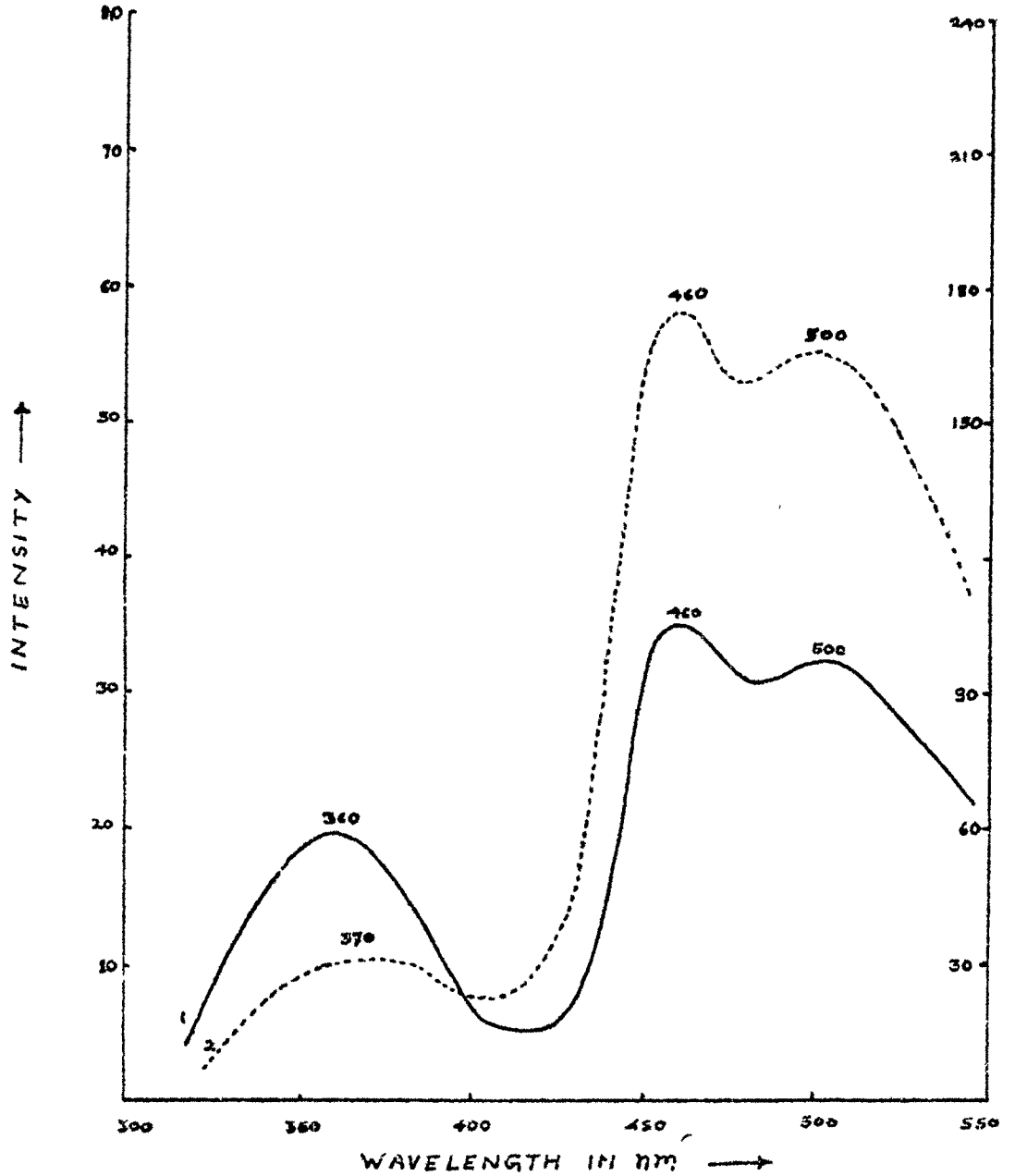
80
70
60
50
40
30
20
10
240
210
180
150
90
60
30
460
500
440
500
360
370
1
2
300
350
400
450
500
550
INTENSITY
WAVELENGTH IN nm

FIG. 43