"A REPORT OF THE TESTS PERFORMED ON THE ZEISS Hα FILTER"

by

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A REPORT OF THE TESTS PERFORMED ON THE ZEISS Hα FILTER

Introduction

This report contains the description and results of tests performed on the Zeiss type "A" Hα filter. No information on the theory of the filter is included here; if the reader is unfamiliar with the optics of the instrument the following references will be helpful. A chapter by Evans [2] treats the basic theory of the filter. Another article by Evans [1] gives a detailed discussion of the filter and methods by which the wavelength of transmission can be tuned. The reference edited by Kuiper provides a bibliography with further references.

1. Evans, J. W. Journ. Opt. Soc. Amer. 39, 229.
2. Kuiper, ed. The Solar System Vol. 1, see Birefringent Filters, by J. W. Evans.

Summary

The tests performed on the $H\alpha$ filter were essentially a check on the more important optical properties stated in the specifications for the type "A" instrument. However, an additional value was obtained in that the filter will now be operated with an intimate knowledge of its optical characteristics, a knowledge of the type which the specifications cannot supply. The most important of the results are listed below.

1. The "$\frac{1}{4}$ Å" bandpass setting is actually slightly narrower than $\frac{1}{4}$ Å, while the "$\frac{1}{2}$ Å" bandpass is wider than $\frac{1}{2}$ Å and is squared-off at the top of the profile.

2. The wavelength of transmission is as denoted by the read-out on the filter and is accurate to within limits smaller than the bandpass of the transmittance, i.e., the tuning is accurate.

3. Both desired responses and secondary responses (located ± 32 Å from the desired response) have intensities whose magnitudes are determined by how far their wavelength positions are located from $6564\frac{1}{2}$ Å. At filter settings of $H\alpha \pm 16$ Å, the desired and secondary responses are comparable in intensity.

4. The percentage transmittances of wavelength $6563 \pm .015$ Å for the $\frac{1}{2}$Å and $\frac{1}{4}$ Å bandpasses are 1.6 % and 1.2%, respectively.

5. The ratio of the intensity of the secondary response to that of the desired response becomes objectionably large (for our purposes) for filter settings beyond about $H\alpha \pm 8$ Å, and will limit the filter's use to within that range.

Description of test equipment

The Hα monochromatic filter was tested for those transmission properties which would pertain to its usage in the study of solar flares with a solar telescope. Basically, these properties include:

(1) transmission profiles and possible effects on these profiles by tuning and angle of incident light

(2) wavelength accuracy of tuned settings

(3) measurement of position and relative intensity of the secondary transmittances

(4) percent transmittance of light at wavelength 6563 Å.

Tests for these properties were carried out with a grating spectrograph at the physics department of The Pennsylvania State University.

The lay-out of the major optical components used in the tests is illustrated in figure 1. The light source, either a hydrogen discharge tube or a concentrated-arc lamp, was positioned about twelve inches from a field lens of two-inch diameter which focused the image of the source on the spectrograph entrance slit, located about 60 inches from the lens. The cone of converging light from this lens is similar to that of a lens of focal length 60 inches used with a light source at infinity. The focal ratio of this system is 30, where the angle of incidence to the filter of the light near the edges of the cone is nearly one degree. The angle of incidence for light in the center of the cone was made zero by observing reflections from the entrance interference filter, assuming it was perpendicular to the optical axis.

The spectrograph is of the Czerny-Turner type and utilizes a ten-inch plane grating with 300 lines/mm. used at 9th order, and a camera lens of focal length

8500 mm. The signal is detected by a photomultiplier (whose gain is controlled by adjustment of the cathode voltage) and displayed on a chart recorder which records at the rate of 0.0301 Å/cm of chart at a wavelength of 6563 Å (0.0765 Å/inch of chart). The chromatic resolving power, $\lambda/\Delta\lambda$, of the instrument as used throughout the tests was about 220,000, where $\Delta\lambda = .03$ Å. This indicates that a purely monochromatic signal would appear 1 cm wide on the chart. Thus, the spectral resolution of the spectrograph so far exceeds any features transmitted by the filter that one may neglect convolution products and assume that the tests were performed by a spectrograph with infinite resolving power.

Throughout the tests the wavelength scanning was performed by two methods. A slow, high-resolution scan was achieved by mechanically scanning a small portion of the spectrum (~2 Å) with an optical wedge. Scans made in this manner will here be called "wedge scans", and will be accompanied by a "scan number", which denotes the advancement of a worm gear which moves the wedge. The scan numbers vary from 0 to 1600, with the wavelength increasing with the numbers. Reverse scans (numbers decreasing, wavelength decreasing also) may also be made, in which case attention has been placed on possible "backlash" in the gears. For these tests, "backlash" was negligible.

Rapid scans over larger wavelength ranges (100 Å) can be made by scanning with the grating itself. These scans are denoted "grating scans", and are also accompanied by scan numbers, where the wavelength decreases as the number increases at a rate of 4 numbers /Å. Most of the graphs included here will already have had a conversion from numbers to wavelength.

Description of the tests performed on the Hα filter

Eight distinctly different tests were performed on the Hα filter, using both the $\frac{1}{4}$ Å and the $\frac{1}{2}$ Å bandpass. A description of each of these tests is summarized below.

Test 1: Assignment of a wedge-scan number to wavelength 6563 Å

A hydrogen discharge tube was focused on the spectrograph slit without the filter. Wedge scans of the Hα emission line were then made in order to locate wavelength 6563 Å. Number 770 was chosen to mark 6563 Å. Due to a large line width and an asymmetric profile, the uncertainty in the number assignment is on the order of ± .015 Å (± .5 cm on the charts).

Test 2: Transmission profile with the Hα filter tuned at 6563 Å

Using the white-light source and the Hα filter set at 6563 Å, the relative transmittance was measured over a wedge-scanned range, 6562 Å to 6564 Å. The results are plotted in figures 2 and 3.

Test 3: Relative transmittance of wavelength 6563 Å with the Hα filter tuned over its range, Hα ± 16 A

Using a white-light source (concentrated-arc lamp) and the spectrograph detector set on 6563 Å, the filter was tuned over its entire range in 1/8 Å increments, according to read-out numbers on the filter. The relative transmittance of wavelength 6563 Å for each filter setting was then recorded (see figure 4). The purpose of this test was to determine the amount of stray 6563 Å light that is transmitted when the filter is tuned to observe some other desired wavelength.

Test 4: Checking the Hα filter for tuning accuracy

Using the grating scan (6563 Å located at number 80371) and a scale of four numbers per Å, it was confirmed by inspection that the filter transmitted light at the wavelength denoted by the read-out. There are no data included in the report for this test, as it is merely a confirmation that the filter tuning is indeed accurate. Tuning accuracy may also be checked against the data in test 5, where wavelength positions of both desired transmittances and secondary transmittances have been observed.

Test 5: Grating scans over 6563 ± 40 Å with the Hα filter tuned at various settings

Separate scans over 80 Å of the spectrum were made for each of the filter settings listed below, using a whitelight source.

tuned setting	band pass	
Hα + 0 Å	½ Å	figure 5
+ 16	½	
+ 12	½	figure 6
+ 6	½	
- 16	½	figure 7
- 12	½	
Hα + 0	¼	figure 8
+ 16	¼	
+ 12	¼	figure 9
- 16	¼	

The graphs representing these scans are intended to measure only the relative intensities and positions of the transmittances. The grating scans too rapidly in wavelength for the profiles to be shown. Profiles are tested below (test 6) with the wedge scan. In addition, the relative intensities of the transmittances were determined in a scan separate from the one in which their positions were located. As a rule, the scans for locating the wavelength position of a transmittance were made with high gain voltages, causing the recorder to run off scale. The purpose of the high gain was to locate any possible, small transmittances other than the ones expected. The results of certain scans have been corrected to some common gain voltage, using experimentally determined gain factors between two voltages. It should be mentioned that fluctuations in the level recorded for zero light were very small; in addition, there was good reproducibility of gain factors. This kind of check was made quite often during the tests.

Test 6: Transmission profile with Hα filter tuned at Hα - 16 Å

Using a white-light source and the filter tuned at Hα - 16 Å, a wedge scan was made of the transmission band at both $\frac{1}{4}$ Å and $\frac{1}{2}$ Å bandpass. The purpose of this test was to insure that the profile was not changed in shape and that the bandpass was not widened with the tuning of the filter. Since there was no appreciable change observed, the graphs for this test are not included in the figures.

Test 7: Transmission profiles with angle of incidence

With the Hα filter tuned at 6563 Å, transmission profiles were obtained for both $\frac{1}{4}$ Å and $\frac{1}{2}$ Å bandpasses as in test 3, except that in this test, the angle of incidence for light at the center of the converging f30 cone was made 1° by displacing the lens aperture reflection 2°. A wedge scan of the $\frac{1}{4}$ Å bandpass and centered at 6563 Å and with 0° angle of incidence was taken immediately before inclining the filter in order to insure the position of 6563 Å with the scan numbers. This yielded a check on any changes in the wavelength position of the profile that might possibly occur after introducing an angle of incidence. Since no appreciable changes were observed, the graphs of this test are not included in the figures.

Test 8: Percent transmittance of wavelength 6563 Å

Using a white-light source and the Hα filter set at 6563 Å, recorded values for the intensity of transmitted light of wavelength 6563 Å were taken for $\frac{1}{4}$ Å and $\frac{1}{2}$ Å bandpasses. With a spectrograph bandpass of about .03 Å centered on 6563 Å, the relative intensity of the two filter bandpasses is just the relative heights of the transmission profiles at 6563 Å, which is about 1.3: 1 (see figures 2 and 3).

In principle, the filter would then be removed from the bench and the intensity of the light again recorded. This was achieved by taking several measurements, reducing the gain voltage in steps for each of which gain factors were determined.

Results and conclusions

Test 1: Assignment of a wedge-scan number to wavelength 6563 Å

Number 770 was chosen to mark the center of the Hα emission line, 6563 Å.

Test 2: Transmission profiles

Transmission profiles for both $\frac{1}{4}$ A and $\frac{1}{2}$ Å bandpasses over the spectrum 6562 to 6564 Å are displayed in figures 2 and 3. Grating scans (± 40 Å) are shown in figures 5 and 8. The results indicate that the "$\frac{1}{4}$ Å" bandpass is slightly narrower than $\frac{1}{4}$ Å at the half-power level. The "$\frac{1}{2}$ Å" bandpass, on the other hand, is slightly wider than $\frac{1}{2}$ Å. In addition, the $\frac{1}{2}$ Å response is "squared-off" at the top of the profile and has an asymmetry with greater transmission on the shorter wavelength side (this is probably not a serious effect). The high-gain grating scan (± 40 Å) revealed the presence of very slight responses (and not objectionable) at Hα ± 4 Å for the $\frac{1}{4}$ Å bandpass.

Test 3: Transmittance of wavelength 6563 Å for various tuned filter settings

With the spectrograph set to observe 6563 ± .015 Å, the results seen in figure 4 are equivalent to scanning the transmission profile over a narrow emission line. Other than the light transmitted by the central portions (± 1 Å) of the profiles, there were no responses detected beyond ± 1 Å from 6563 Å for either bandpass during the tuning over the entire range (Hα ± 16 Å).

Test 4: Tuning accuracy

At all filter settings a response was detected at the wavelength denoted by the filter read-out dial. The secondary responses were always located 32 Å from the desired response for all filter settings. One may conclude that the tuning is accurate for all settings to within limits smaller than the bandpass.

Test 5: Grating scans over 6563 ± 40 Å

The relationship between positions and intensities for both desired and secondary responses at both bandpasses are displayed in figures 5, 6, 7, 8, and 9. It should be noted that no secondary responses were seen for a filter setting of Hα. Most important of all, it was observed that when the desired and secondary responses are each positioned 16 Å from 6563 Å, as in the case of setting the filter at Hα - 16 Å (with the secondary response at Hα + 16 Å) or with the filter set at Hα + 16 Å (with the secondary responses at Hα - 16 Å), the intensity of that response at Hα + 16 Å (regardless of whether or not it was the desired or secondary response) was the brighter by a factor of 1.4 to 1.5. This was found to be true for both bandpasses.

Test 6: Transmission profiles at Hα - 16 Å

Results (not presented in the figures) show that the transmission profiles for both bandpasses are not significantly changed when the filter is tuned to Hα - 16 Å. One may probably assume that the profiles are also unchanged for other filter settings.

Test 7: Transmission profiles with angle of incidence

Results (not presented in the graphs) show that the profiles for both bandpasses are not significantly changed when the angle of incident light is made about 1° for the center of the f30 cone. Since the f30 field lens already introduces an angle of incidence of 1° for light at the edge of the cone, the filter was therefore being used at an angle of incidence of about 2° for at least some portion of the incident light.

Test 8: Percent transmittance

Using a spectrograph bandpass of .03 Å centered on 6563 Å, the percent transmittance at the peak of the band of the $\frac{1}{2}$ Å and $\frac{1}{4}$ Å bandpasses were 1.6% and 1.2%, respectively. However, the total power transmitted by the entire profiles for the two bandpasses must be different by a factor of about 3.2, which is evident from the area under the transmission profile curves.

Plotting the intensity of the responses for the $\frac{1}{2}$ Å bandpass (desired and secondary) against their wavelength position yields the points in figure 10. To an approximation, these points lie on a $\cos^2 \theta$ curve whose peak is centered at about Hα + $1\frac{1}{2}$ Å. This asymmetric effect may be caused by the dielectric entrance filter having a transmission centered not on Hα but on Hα + $1\frac{1}{2}$ Å. The ratio of the intensity of the secondary response to that of the desired response may be estimated by the following procedure: to obtain the intensity of the desired response, take the value of the curve above the filter setting; the intensity of the secondary response is then represented by the value of the curve above a wavelength position ± 32 Å from the desired response. Plotting the above ratio against its corresponding filter setting yields the curve shown in figure 11. At wavelength positions where actual experimental intensities were measured, the corresponding points have been denoted "experimental" in figure 11. Other points obtained by using the values of the $\cos^2 \theta$ curve have been denoted "theoretical". Figure 11 represents the most important aspect of the results --- namely a determination of the wavelength range over which the filter can be used. For solar photographic work it is probably essential that the ratio of the secondary response to the desired response be no larger than 0. 1. This criterion allows tuning the filter over a range no larger than Hα - 8 Å to Hα + 10 Å.

Figure 1

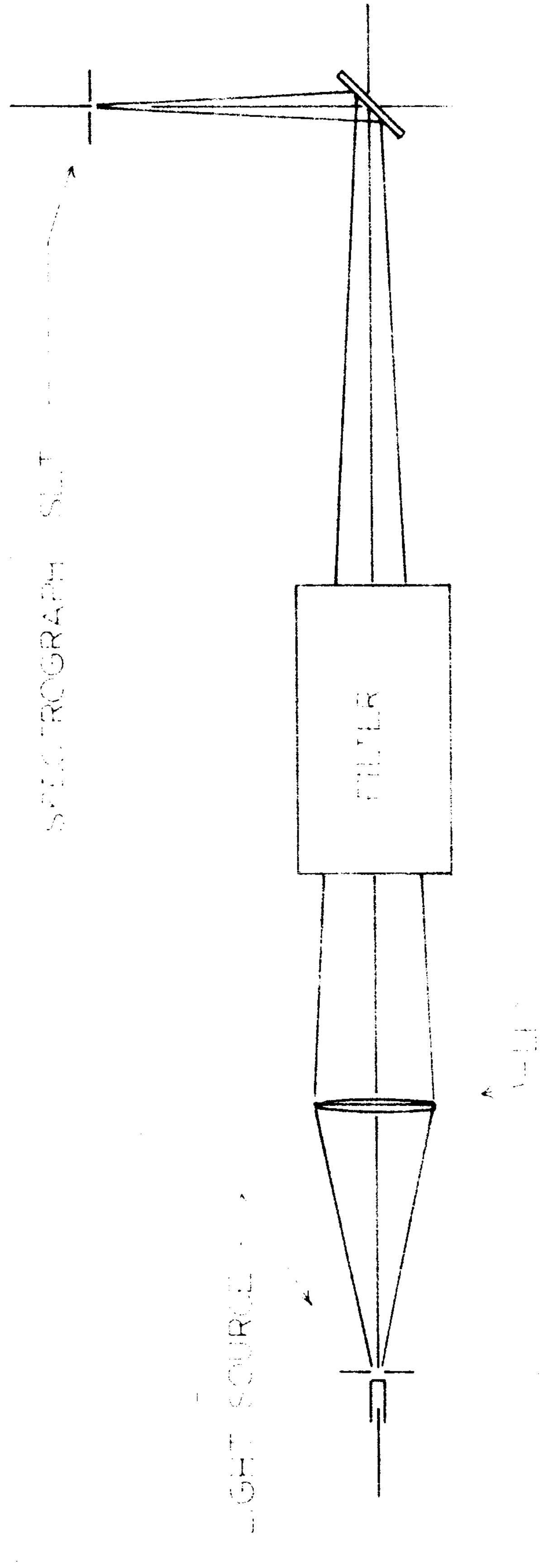
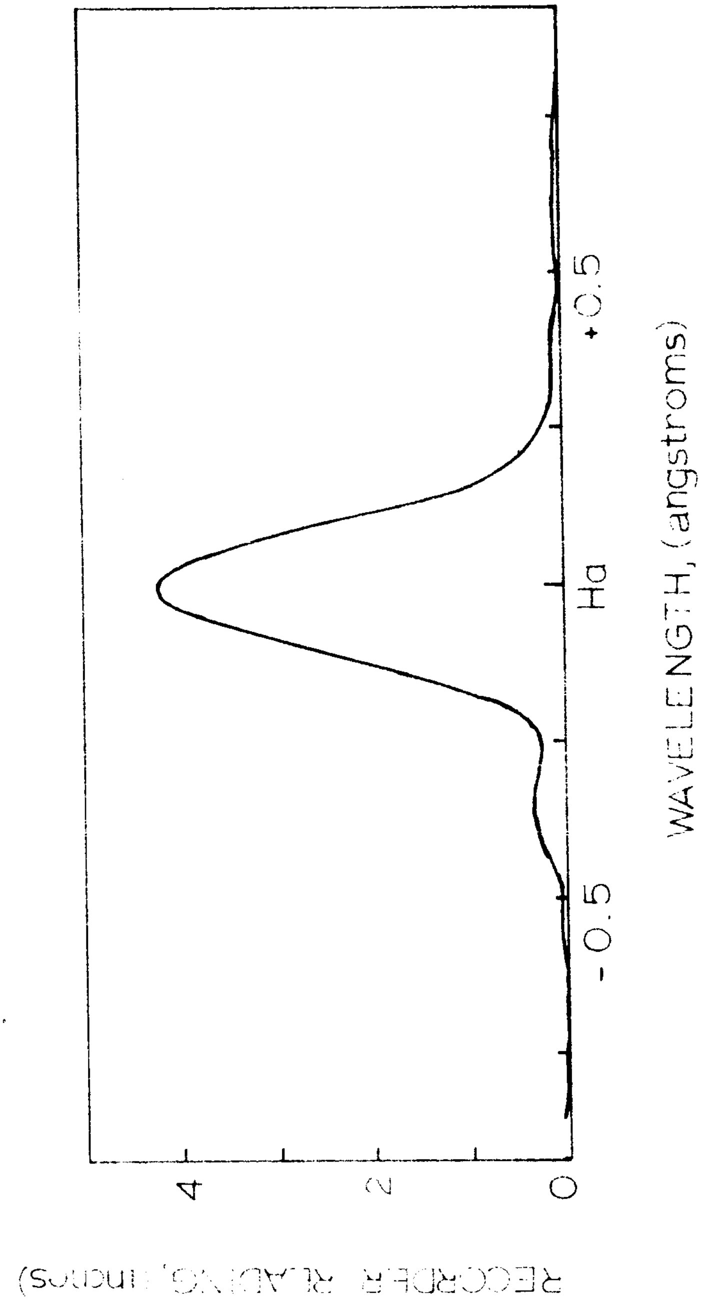


Figure 2



RECORDER READINGS, (inches)
0
2
4
WAVELENGTH, (angstroms)
- 0.5
Hα
+0.5

Figure 3

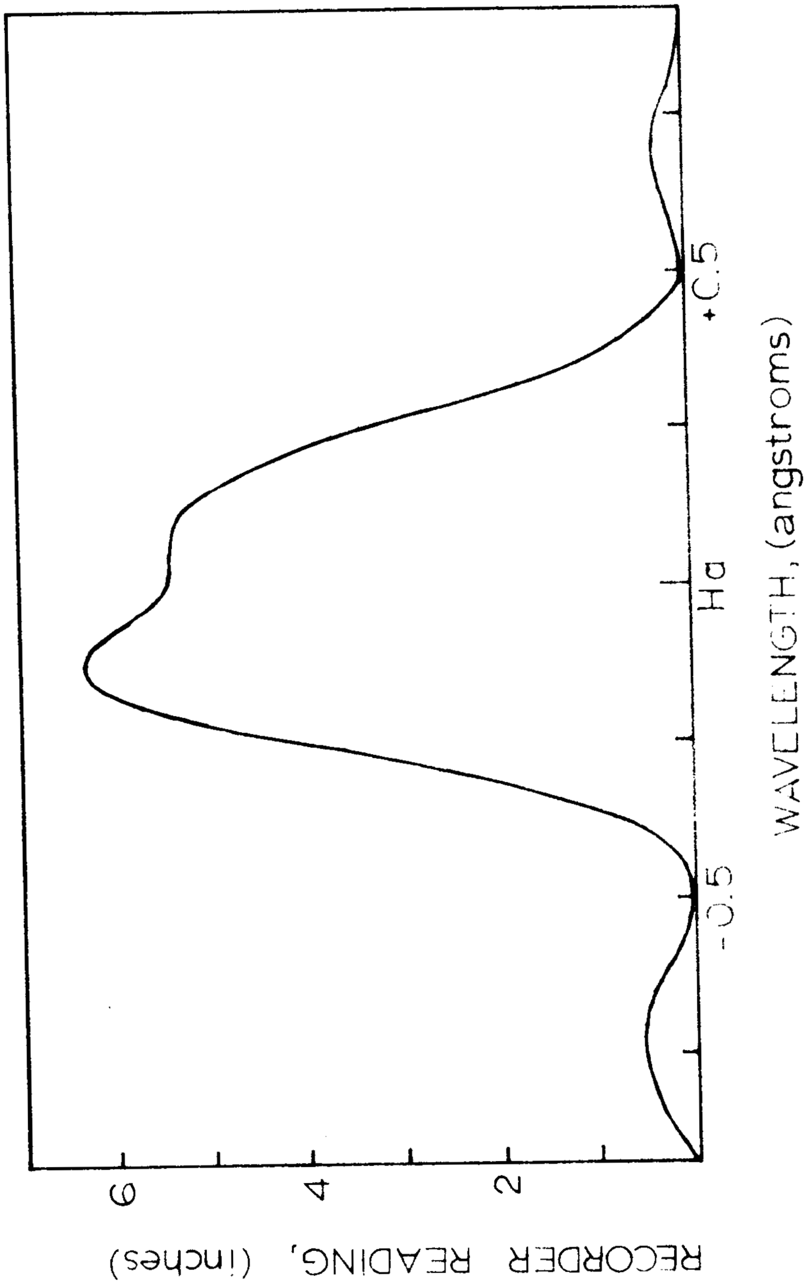
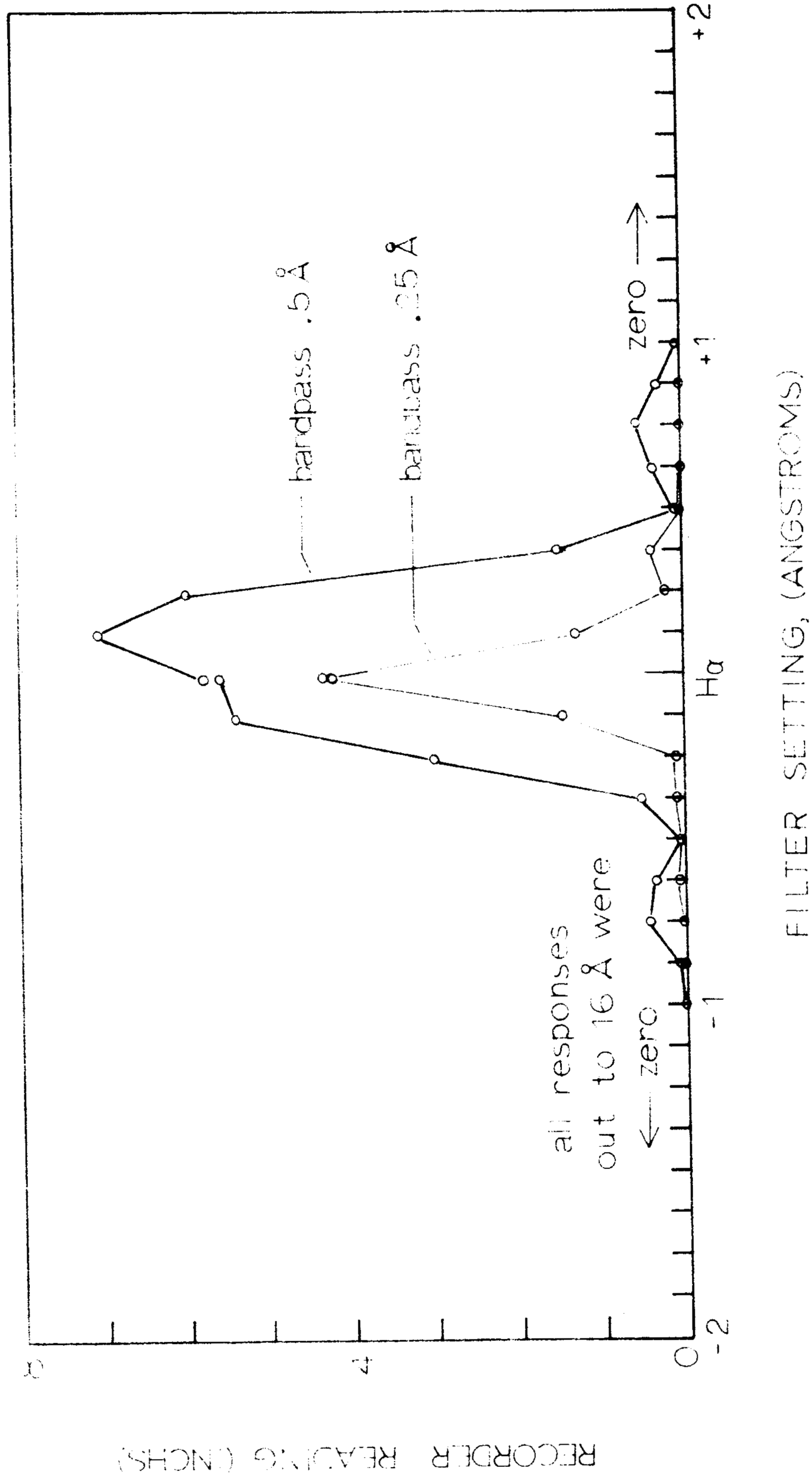


Figure 4



bandpass .5 Å
bandpass .25 Å
all responses out to 16 Å were ← zero
zero →
-2
-1
Hα
+1
+2
FILTER SETTING, (ANGSTROMS)
0
4
8
RECORDER READING (INCHES)

Figure 5

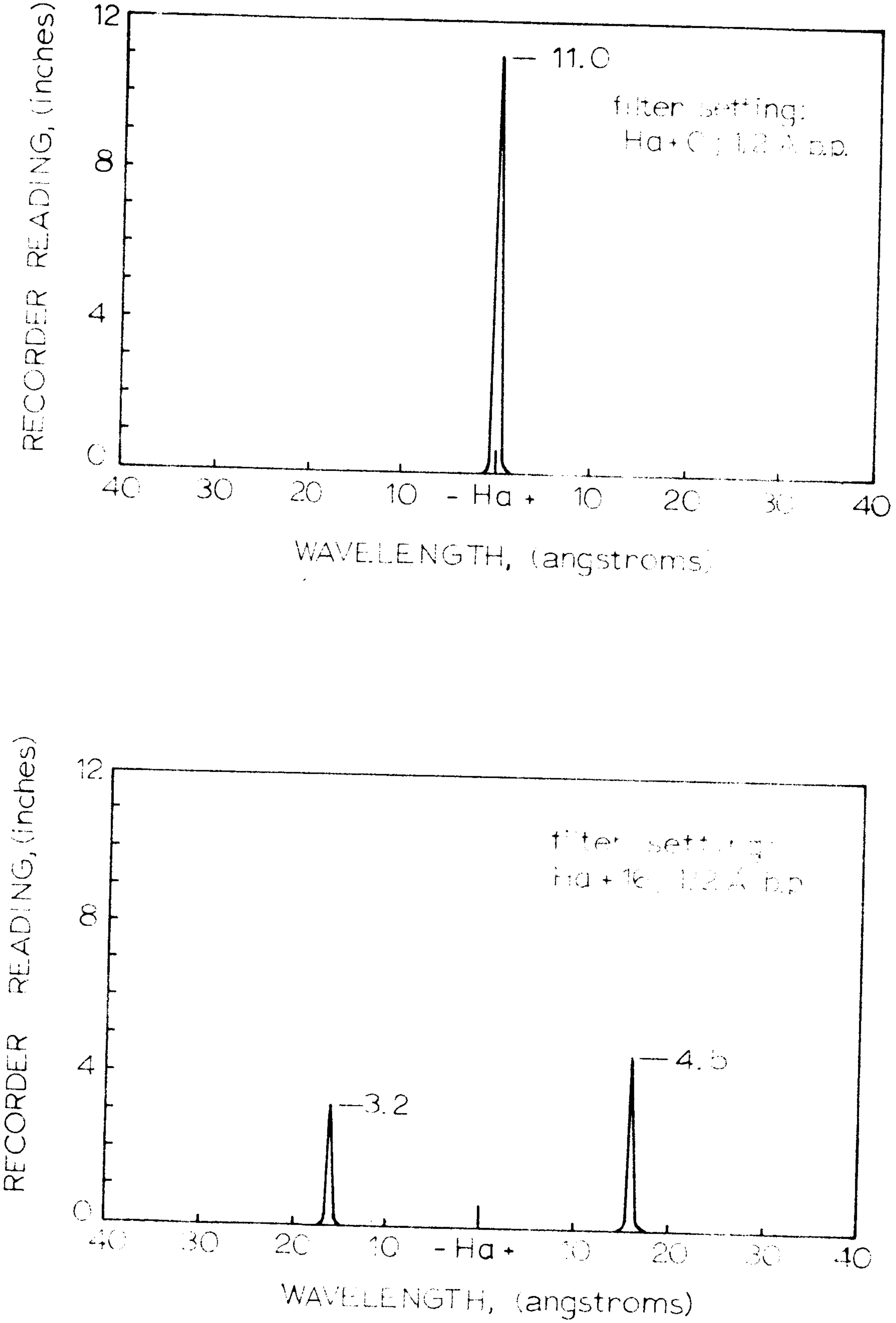
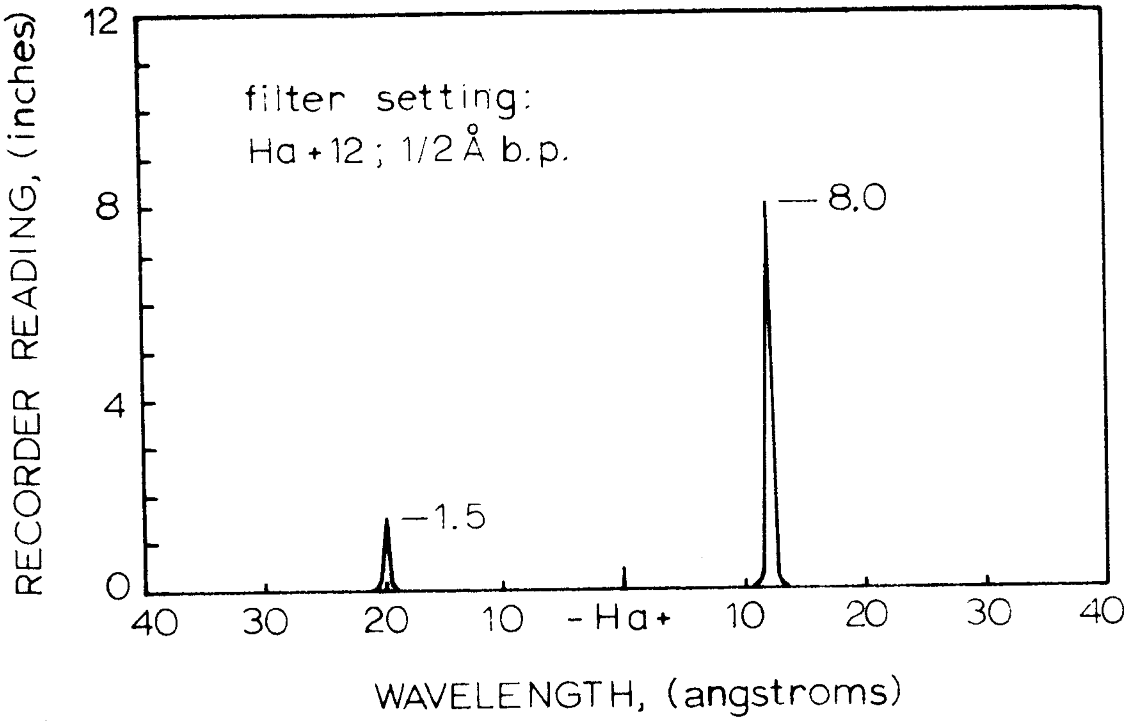

RECORDER READING, (inches)
12
8
4
0
— 11.0
filter setting:
Ha + 0; 1.2 Å b.p.
40
30
20
10
- Ha +
10
20
30
40
WAVELENGTH, (angstroms)
RECORDER READING, (inches)
12
8
4
0
filter setting:
Ha + 16; 1.2 Å b.p.
—3.2
—4.5
40
30
20
10
- Ha +
10
20
30
40
WAVELENGTH, (angstroms)

Figure 6


filter setting:
Ha + 12 ; 1/2 Å b.p.
RECORDER READING, (inches)
12
8
4
0
8.0
1.5
40
30
20
10
- Ha +
10
20
30
40
WAVELENGTH, (angstroms)

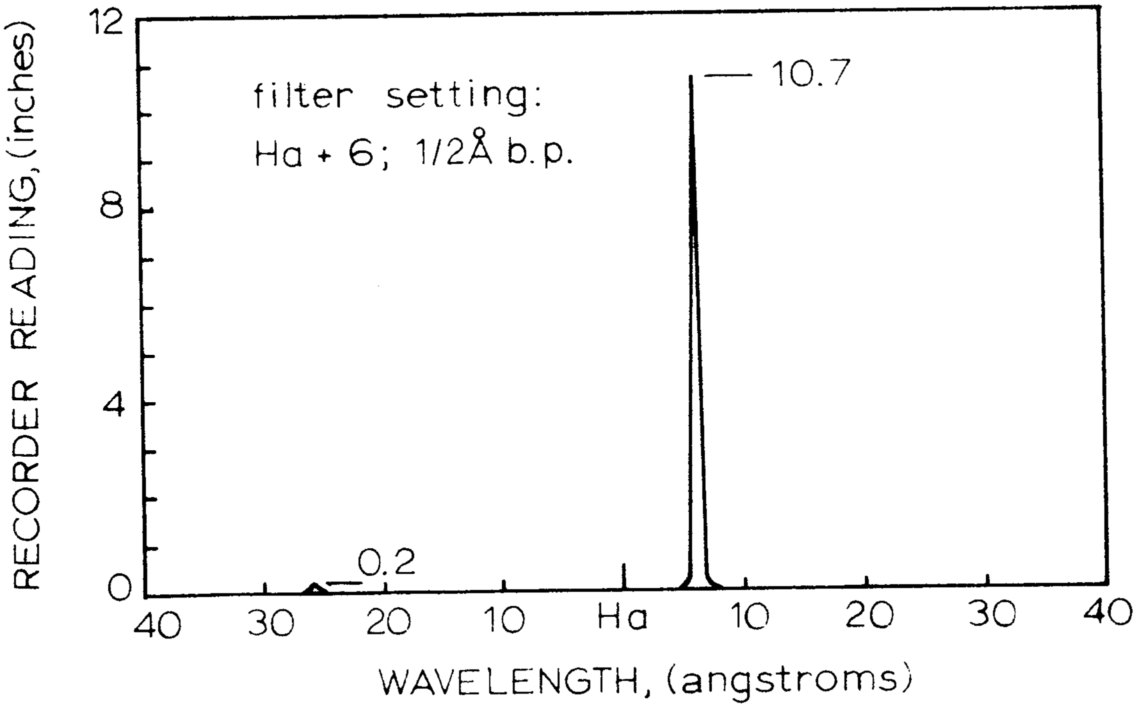
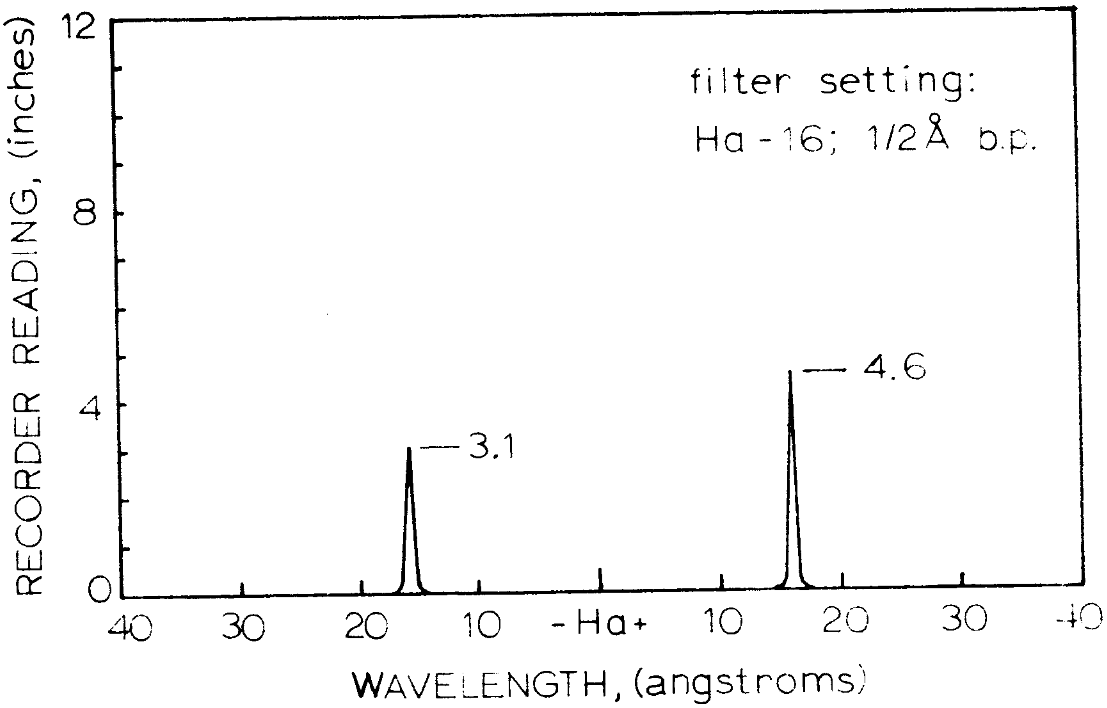
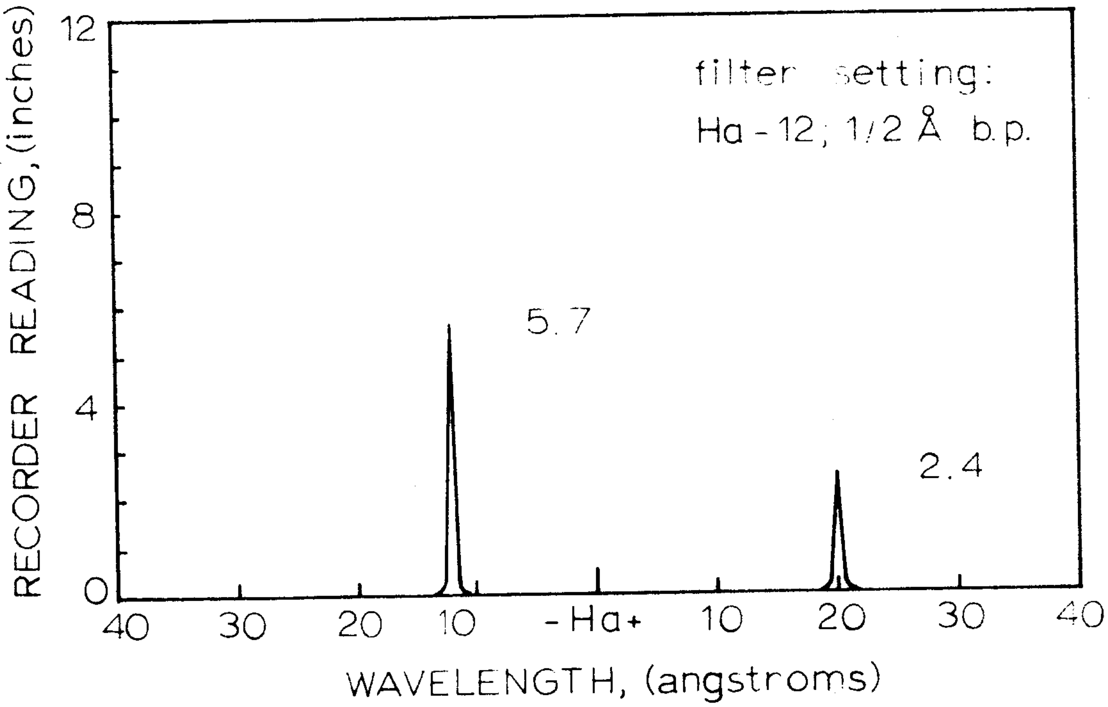

filter setting:
Ha + 6; 1/2Å b.p.
RECORDER READING, (inches)
12
8
4
0
10.7
0.2
40
30
20
10
Ha
10
20
30
40
WAVELENGTH, (angstroms)

Figure 7

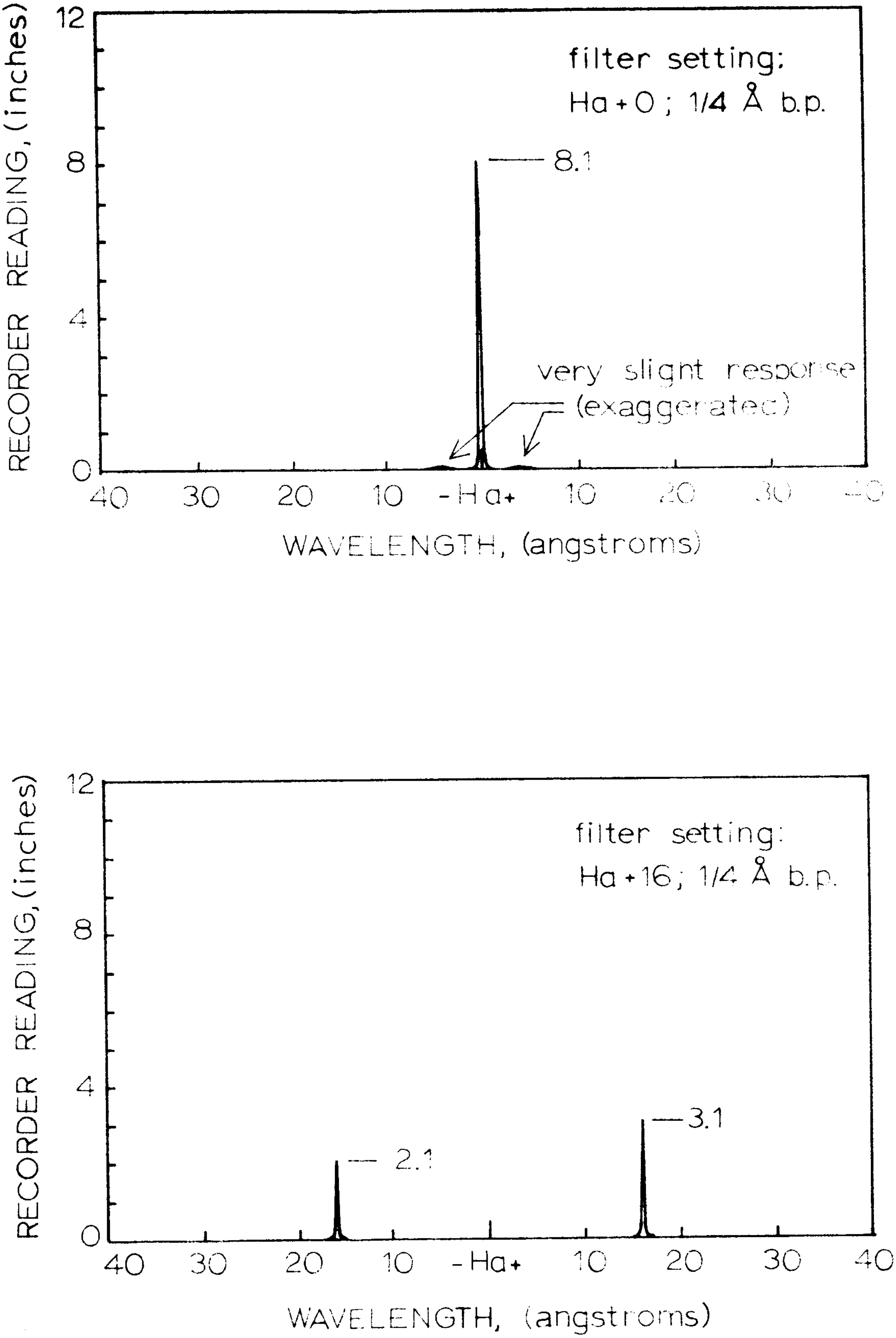


filter setting:
Hα - 16; 1/2Å b.p.
RECORDER READING, (inches)
12
8
4
0
3.1
4.6
40
30
20
10
- Hα +
10
20
30
40
WAVELENGTH, (angstroms)



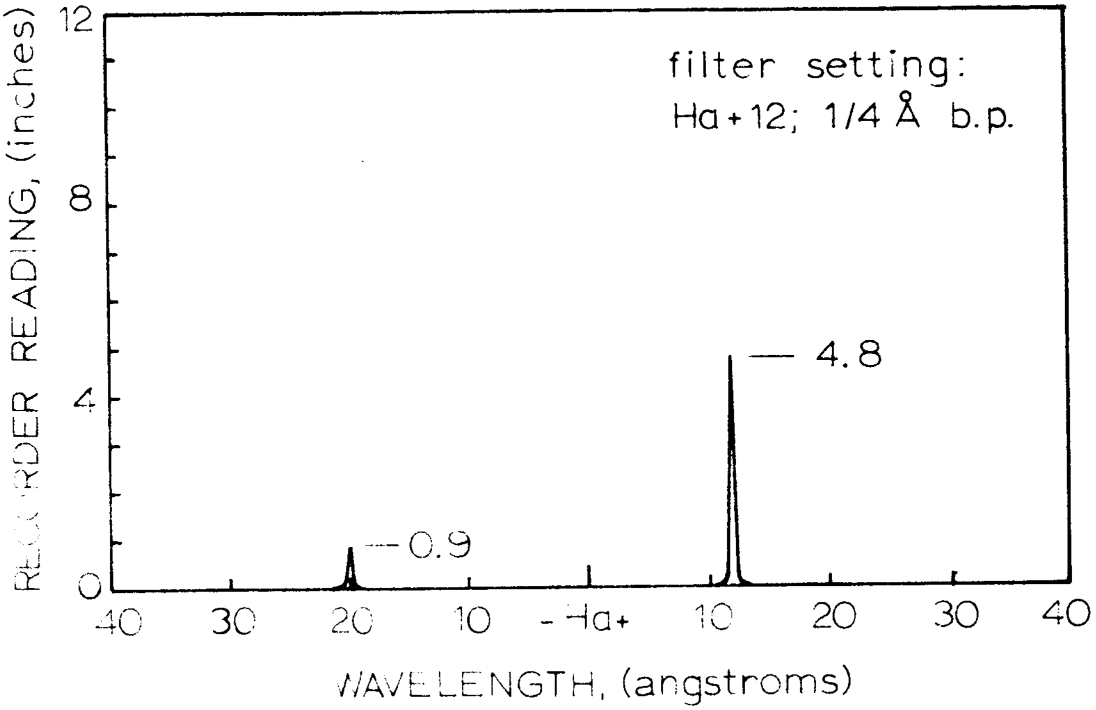
filter setting:
Hα - 12; 1/2 Å b.p.
RECORDER READING, (inches)
12
8
4
0
5.7
2.4
40
30
20
10
- Hα +
10
20
30
40
WAVELENGTH, (angstroms)

Figure 8



RECORDER READING, (inches)
12
8
4
0
filter setting:
Ha + 0 ; 1/4 Å b.p.
8.1
very slight response (exaggerated)
40
30
20
10
- Ha +
10
20
30
40
WAVELENGTH, (angstroms)
RECORDER READING, (inches)
12
8
4
0
filter setting:
Ha + 16 ; 1/4 Å b.p.
2.1
3.1
40
30
20
10
- Ha +
10
20
30
40
WAVELENGTH, (angstroms)

Figure 9


filter setting:
Hα+12; 1/4 Å b.p.
4.8
0.9
RECORDER READING, (inches)
12
8
4
0
40
30
20
10
- Hα+
10
20
30
40
WAVELENGTH, (angstroms)

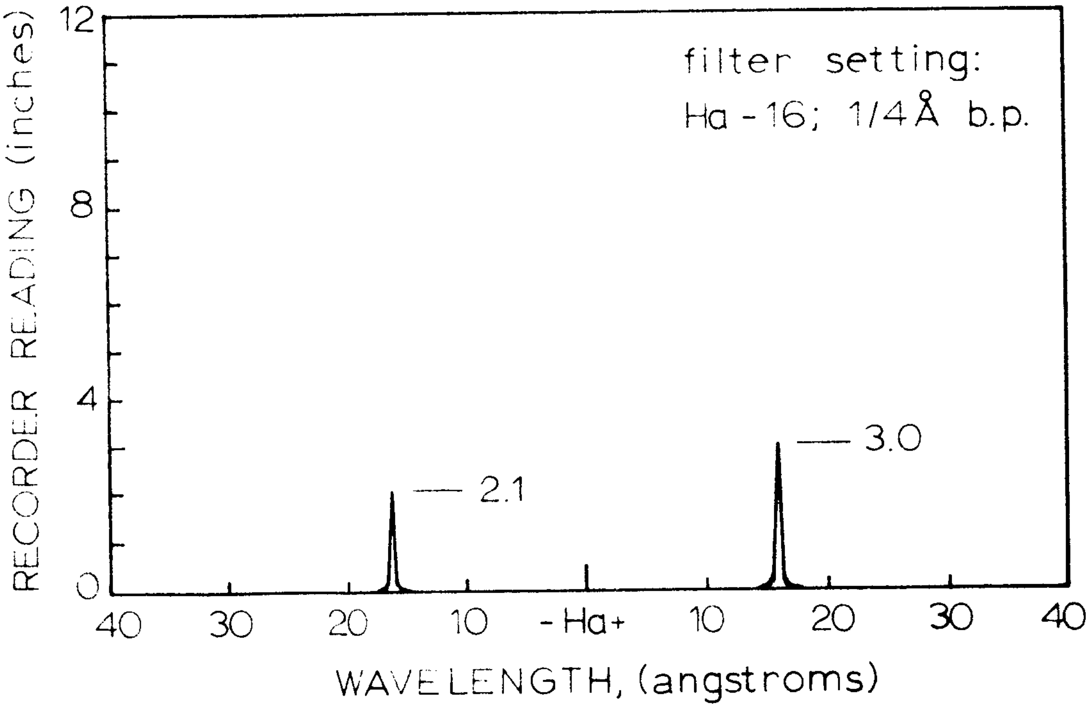
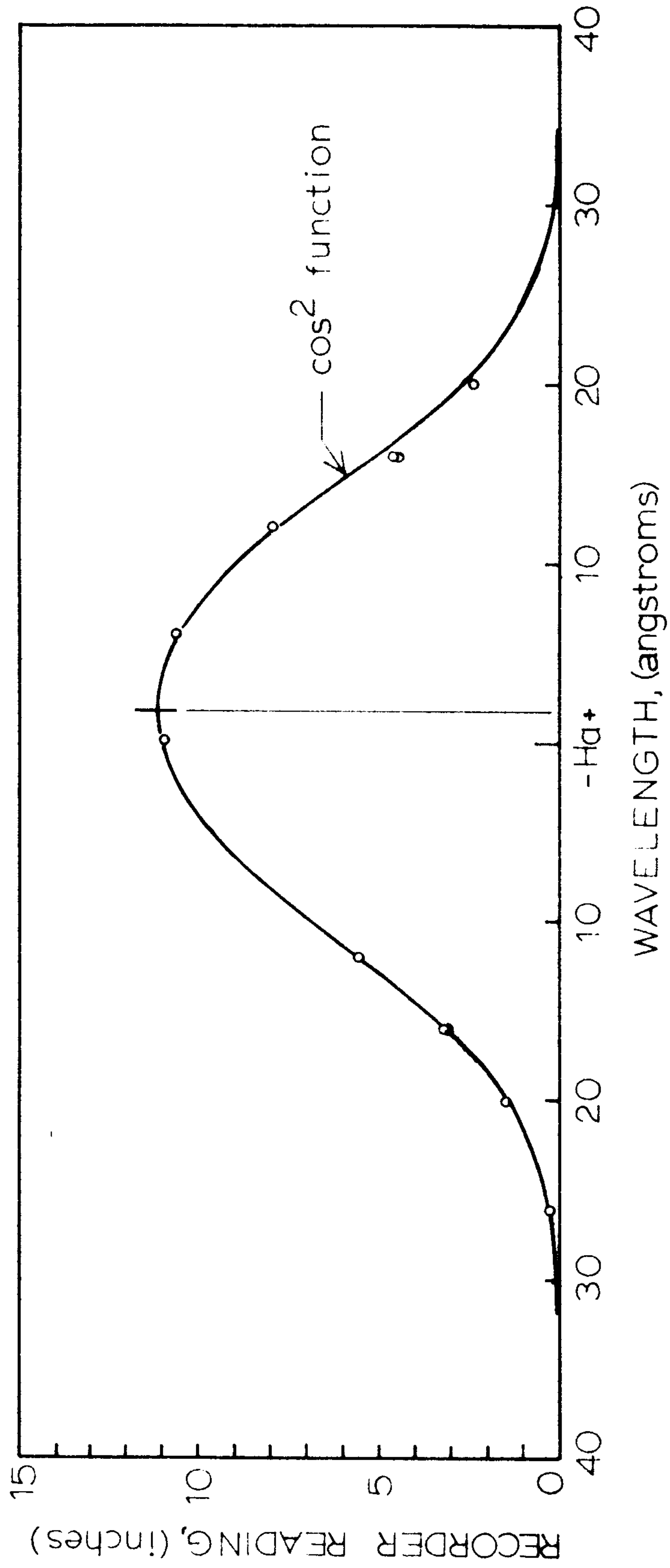
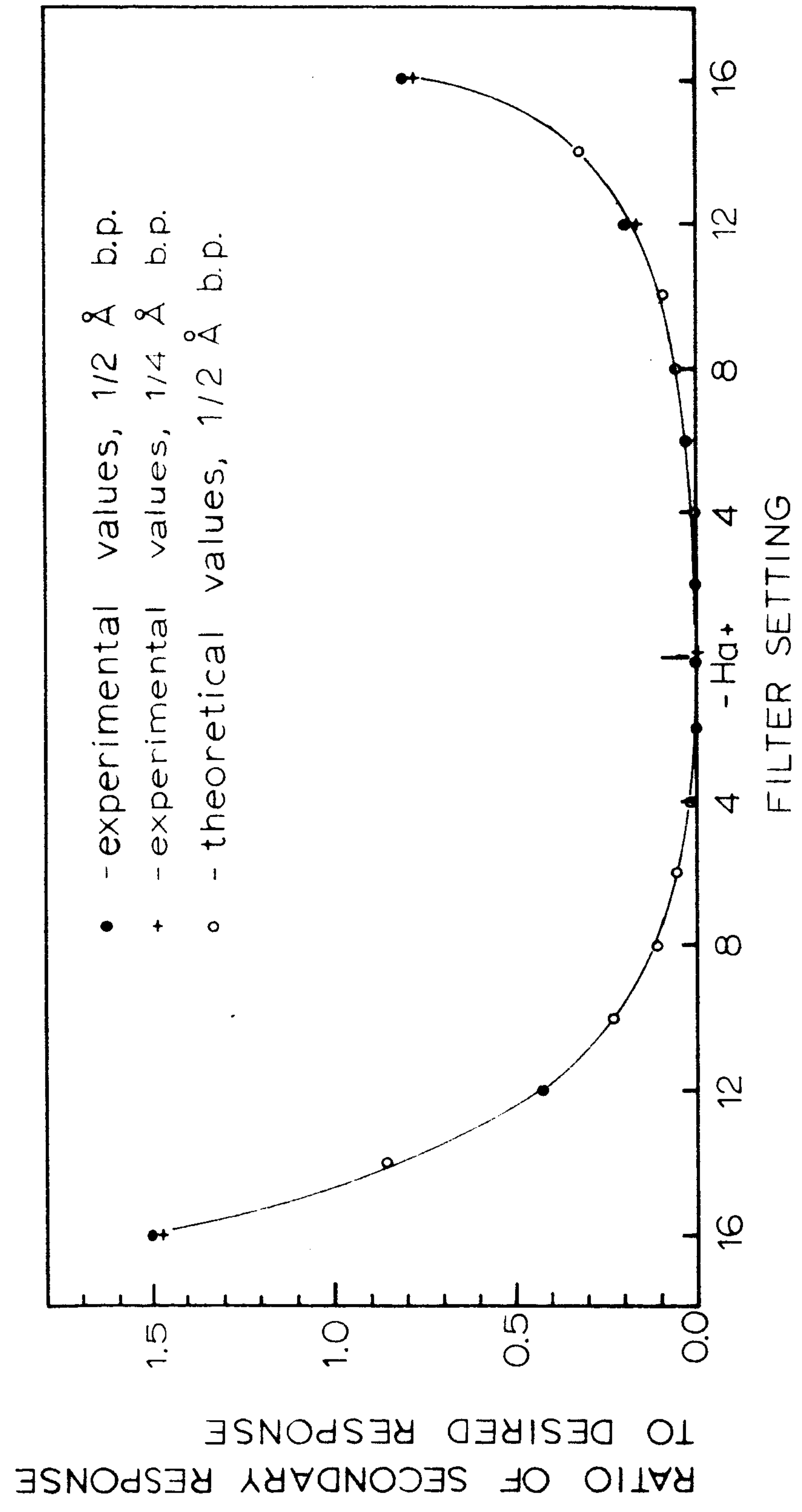

filter setting:
Hα-16; 1/4 Å b.p.
3.0
2.1
RECORDER READING (inches)
12
8
4
0
40
30
20
10
- Hα+
10
20
30
40
WAVELENGTH, (angstroms)

Figure 10



RECORDER READING, (inches)
0
5
10
15
40
30
20
10
-Hα+
10
20
30
40
WAVELENGTH, (angstroms)
cos² function

Figure 11


● - experimental values, 1/2 Å b.p.
+ - experimental values, 1/4 Å b.p.
○ - theoretical values, 1/2 Å b.p.
RATIO OF SECONDARY RESPONSE TO DESIRED RESPONSE
0.0
0.5
1.0
1.5
16
12
8
4
-Hα+
4
8
12
16
FILTER SETTING