CHAPTER V

VELOCITY AND BRIGHTNESS OSCILLATIONS

5.1. Analysis of Brightness oscillations

I have studied the intensity fluctuations in the continuum and in the line wings and core of FeI 6358.695 line of the sequence A1082. The continuum is exposed to a degree very favourable for studying the brightness fluctuations. Only 62 out of 120 frames were chosen for intensity measurements. Measurements were made from the microphotometer traces. During the measurements on the line wings, the microphotometer slits were located practically at the same $\pm \Delta \lambda$ value as in the velocity measurements. The width of the microphotometer slit was smaller than that of the comparator and was located central to it. Because of this, the depth averaging is less in the intensity measures. In the steep parts of the profile, the intensity fluctuation is the sum of the contributions from the intrinsic variation in intensity and from the Doppler shift. The effect of the Doppler shifts were eliminated by averaging the traces at $+ \Delta \lambda$ and $- \Delta \lambda$. 
From the microdensitometer traces, intensities were derived via the characteristic curve. The intensity data of the continuum, line wing and line core were read off at intervals of 1030 km on the sun. The fiducial line for stepping off this interval was again the shadow of the hair line on the spectrograph slit. This procedure ensured that the intensities read off and the earlier velocity measurements pertain to the same region on the sun. These intensity measurements are with reference to an arbitrary zero. As in the case of velocities, a mean line was fitted to each one of the I (x) curves which are the intensity run along the length of the spectral line. The mean line was provided by the average of the intensity measures of 62 frames. Then the quantity I (x) - $\bar{I}$ (x) = $\Delta I$ (x) was read off at the 61 points. With these, the ratio $\Delta I (x)/\bar{I} (x)$ was computed for the 61 points, which gave the fluctuating component of the intensity. This procedure gave for all the three sets, values of

$$\frac{\Delta I}{I_{\text{cont}}}$$, $$\frac{\Delta I}{I_{\text{wing}}}$$ and $$\frac{\Delta I}{I_{\text{core}}}$$.

Each set consists of an array with 61 rows and 62 columns. These are shown as a two dimensional plot i.e. as functions of position on the sun and time in Figure V-1. The fluctuations in the
FIGURE V-1

Sample plot of intensity fluctuations vs time and position in the continuum and in the line wing and core of FeI 6358.695. The individual curves represent intensity at consecutive points separated by 1080 km on the sun.
continuum are the weakest and appear to be random in nature. The fluctuations in the line wing have a close resemblance to those in the continuum. In the line core, the variations are striking and resemble the quasi-periodic oscillations of velocities. I then obtained the power spectra of the three groups of intensities by the methods described in Chapter III for velocity power spectra. The power spectra are shown in Figures V-2 to V-4.

The continuum intensity power spectrum starts with maximum power at zero frequency falling off rapidly at higher frequencies as is typical of convective motion. It shows a definite, but a very weak oscillatory component at $v = 3.5 \times 10^{-3}$. Edmonds and McCullough (1966) have studied this feature in their analysis of the granulation brightness fluctuations using several sets of data. They have arrived at the conclusion that in the granulation, a maximum of about 2 per cent of the total fluctuating power is contributed by the oscillatory mode.

The power spectrum of the line wing variations resembles that of the continuum, with maximum power at the zero frequency and with a weak oscillatory component at
Power spectrum of the intensity fluctuations in the continuum. Most of the power is concentrated near the very low frequencies. The weak oscillatory component is seen at $\nu = 3.5 \times 10^{-3}$ Hz.
Continuum $\Delta I_c/I_c$

Fig. V - 2
Power spectrum of the intensity fluctuations in the wing of FeI 6358.695 line. The curve resembles the continuum curve with a weak oscillatory component at $\nu = 3.5 \times 10^{-3}$ Hz.
Wing brightness

Fig. V - 3
Power spectrum of the intensity fluctuations in the core of FeI 6358.695 line. The peak in the power at $\nu = 3.5 \times 10^{-3}$ Hz is very prominent, showing the predominance of the oscillatory component.
Fig. V-4

6358.695

Core brightness
\( \nu = 3.5 \times 10^{-3} \) Hz. The brightness fluctuations in the line core have a power spectrum characterised by two regions where the power is concentrated. One is near the zero frequency range and another at \( \nu = 3.5 \times 10^{-3} \) Hz, which is the resonance range in the corresponding velocity field. These findings are in good agreement with the earlier observations on the continuum and cores of strong lines by Evans et al. (1963). The high power near the zero frequency is obviously due partly to the convective motions also noticed in the velocity field power spectra as well as due to the presence of "persistent features" as interpreted by Evans et al. (1963).

5.2. Cross-spectral analysis of Intensity fields

The brightness fluctuations in the wings of FeI 6358 and in the line core were cross-correlated with those in the continuum and their coherence and phase spectra were computed. These are shown in Figures V-5 and V-6. The wing and the continuum show a high coherence in general. In the low frequency range the coherence reaches a value as high as 0.95. In the range \( \nu = 2.0 \) to \( 4.0 \times 10^{-3} \) the wing brightness lags behind the continuum by about 14° or 12 sec. The lag noticed by Edmonds et al. (1965) between the fluctuations in the central intensity
Figure V-5

Coherence and phase spectra of the wing brightness fluctuations in FeI 6358.695 against continuum. Around $\nu = 3.0 \times 10^{-3}$ Hz, the wing brightness lags behind the continuum by about 130°.
Fig. V-5
Coherence and phase spectra of the core brightness fluctuations in FeI 6358.695 against continuum. The core brightness leads the continuum by $57^\circ$ in the range $\omega = 2.0$ to $5.0 \times 10^{-3}$ Hz.
Fig. V-6
\( \Delta \omega/\omega \) of CII 5052 and the continuum is about 12 seconds. It is reasonable to expect that wings of FeI 6358 and the core of CII 5052 are formed almost at the same levels and should show similar lags with reference to the continuum.

Between the core and continuum brightness, the coherence has a peak of 0.88 near the zero frequency. This high coherence gives more weightage to the presence of convective motions at these levels. The coherence elsewhere drops down to an average of 0.65. The core brightness is seen to lead the continuum over the entire frequency range and has a value of 57º at \( \nu = 3.5 \times 10^{-3} \) Hz. This lead, suggests that the source of temperature fluctuations in the line wings (or in the cores of weak lines) and in the core of strong lines, is different. This behaviour of the brightness variations has been interpreted in terms of the radiative relaxation time by, Noyes and Leighton (1963). The thermal relaxation time for a thin atmosphere approximation is given by

\[
\tau = \frac{3}{32} \frac{k}{m} \frac{1}{T^3} \kappa(2)
\]

where \( k(z) \) is the Planck mean absorption coefficient per gram of hydrogen, \( T \) is the temperature, and \( 1/k \) is a characteristic length of the perturbation (Spiegel 1957).
This assumption is valid for regions of \( \tau_c \ll 1 \).

The relaxation time at different altitudes have been calculated by Hayes and Leighton (1963) with this relation. The relaxation time is only of the order of a few seconds in the lower levels due to the relatively high concentration of \( \pm \)ion, which is the main source of opacity. At very high levels, the concentration of \( \pm \)ion falls off and the relaxation time rises to hundreds of seconds. Thus, the thermal properties of lines originating in the deeper layers of the photosphere i.e. weak lines and wings of strong lines are controlled by the ambient radiation field which is the intensity pattern of the granulation. Hence the brightness variations at these levels lag behind those in the continuum. The atmosphere at these levels does not respond to the compressional changes of pressure and density induced by the velocity oscillations. The radiative relaxation time is very small compared to the period of oscillation and hence any temperature perturbations so caused are smoothed out. This smoothing out of these perturbations renders the temperature field practically isothermal. Thus, we do not expect the power spectrum curves for the continuum, cores of weak lines or wings of strong lines to show any significant level of power in the 5-minute period range.
At higher levels, the thermal fluctuations are no longer controlled by those of the granulation, due to high radiative relaxation time and this renders the changes in temperature adiabatic. At these levels, the temperature changes are caused by the compressional forces induced by the velocity oscillations.

5.3. Cross-spectra analysis of velocity and intensity fields.

To study this aspect, I have computed the coherence and phase spectra of the velocities of 4 lines with the continuum brightness fluctuations of the sequence A1082. The four lines chosen for this analysis are FeI 6338.588, NiI 6339.125, FeI 6335.345 and FeI 6358.695. The velocity data for these lines consist of 120 columns, whereas all the intensity measurements have been restricted to 62 frames which will give only 62 columns in the intensity data. So, in this analysis the intensity data have been cross-correlated with the velocities from the corresponding frames, keeping the length of the two groups of data identical. The coherence and phase are shown in Figures V-7 to V-10. The results for the four lines are almost similar. The coherence is about 0.65 in the resonance range. On either side of this range, the coherence
Coherence and phase spectra of the velocity fields in

FeI 6338.588
NiI 6339.125
FeI 6335.345
and FeI 6358.695

against brightness fluctuations in the continuum. In the range 1 to $4 \times 10^{-3}$ Hz., the velocities in all the lines lag behind the continuum features.
Fig. V - 7

6338.588V - Continuum
Fig. V - 8
fluctuates about a mean value of 0.6. This value of coherence is an evidence for the close association of upward velocities and brightenings in the continuum. In the frequency range $\nu = 0$ to $4 \times 10^{-3}$, the upward velocities lag behind the brightenings in the continuum by about 34 to 38°. This agrees well with the lags obtained by Evans et-al (1963) for FeI 5171 line and by Edmonds et-al (1965) for CrI 5051.9. It is interesting to note that Evans and Michard (1962) from a qualitative study of the films estimated, "that the appearance of a strong bright feature in the continuum is followed by an oscillation in the lines (FeI 5171 and MgI 5172) initiated by a violet shift, and that the first velocity maximum occurs about 40 seconds after the maximum brightness in the continuum feature". The phase somewhat reverses its sign in the region of high frequencies. In the low frequency part, all the four lines show a very consistent phase lag between upward velocity and bright continuum features. This is very consistent with the phase relationship to be expected in convective motions too, which prevail in this frequency range. Edmonds et-al (1965) found the phase reversed, in this region.
Finally, I have cross-correlated the velocity measurements in the line FeI 6358.695 with (i) core brightness and (ii) wing brightness in the same line. The phase and coherence spectra of these are plotted in Figures V-11 and V-12. In the case of velocity Vs core brightness curve, the coherence has a mean value around 0.7 from $\nu = 2$ to $5.5 \times 10^{-3}$. In the low frequency region, the coherence rises to 0.85 and beyond $\nu = 5.5 \times 10^{-3}$ it drops to about 0.4 and rises again. The intensity oscillation in the core leads the velocity oscillation by about 93°.5. This agrees with the findings of Evans et-al (1965) on the FeI 5171 line and also those of Frazier (1968) and Tannenbaum et-al (1969). Of course, it must be agreed that the two oscillations compared here pertain to two different levels; but the justification is from the earlier argument that the temperature oscillations in the core of strong lines are caused by the compressive motions induced by these velocity oscillations themselves. The atmosphere, at these levels, possessing a high value for the radiative relaxation time, behaves adiabatically and so the changes in temperature, pressure and density are all in phase. Now, for a standing wave the velocity oscillations lag the temperature and pressure
Coherence and phase spectra of the velocity fields against the core brightness in FeI 6358.695. The velocity oscillations lag behind the brightness fluctuations by 93°.
6358.695 V - Core brightness

Fig. V-11
Coherence and phase spectra of the velocity fields against the wing brightness in FeI 6358.695. In the range $\nu = 0$ to $5 \times 10^{-3}$ Hz., the velocity lags behind the wing brightness by about 21°.
Fig. V-12

Coherence

Phase

6358.695V - Wing brightness

\[ \pi/2 \]

\[ -\pi/2 \]
oscillations by $90^\circ$ (Whitney 1958). Hence, the phase relations observed above confirm the existence of the standing wave motion. That standing waves exist in this range of frequencies were shown earlier in Chapter IV by the insignificant phase lag between the velocity fields of lines originating at different heights.

The velocity lags behind the wing brightness by about $21^\circ$ near $\nu = 3.5 \times 10^{-3}$. With the continuum the phase lag of the velocity is $38^\circ$. This supports the argument that the changes in the line wing brightness reflect only those of the continuum, for the phase lag of $21^\circ$ resembles the phase lag between the velocity and the continuum with allowance made for the radiation field to reach the level of the wings.