GENERAL DISCUSSION

Newkirk: The observations I will now show from Skylab are relevant to the question raised somewhat earlier about the connection between the chromosphere, the transition region, and the overlying corona. The slide is provided by the Harvard College Observatory, far ultraviolet experiment. It shows an area of the Sun with images in Ly-α, C III and Mg X. Bright points are visible in all three of the images. However there is a portion of a coronal hole which you can see. Within the coronal hole, the bright points appear to be suppressed somewhat in the coronal line of Mg X. One interpretation that might be placed on this is that the coronal holes are regions where the magnetic field is open to the interplanetary medium, so that what we are seeing in the coronal hole is a region in which the high effectiveness of conductivity outward into space is able to cause a depletion of the corona even though the bright points continue to show from the chromosphere through the transition region into the corona. This has relevance to the type of model suggested by Dr Gabriel.

Schmidt: Did I understand correctly that you stated that the connection to interplanetary space is restricted to these coronal holes; if so, how about the magnetic field balance in the interplanetary space?

Newkirk: I am not sure I understood your question, but we may consider the polar corona as being coronal holes and there we clearly do not have to worry about any flux balance in interplanetary space.

Schmidt: But are you implying that only the coronal holes are connected to interplanetary space, and no other regions on the Sun?

Newkirk: I think that would be hazardous.

Schmidt: You only say that these regions are connected.

Newkirk: These regions are connected to interplanetary space in a much more effective way. The solar wind has to do much less work in plowing its way out of the Sun. Where the field is more or less unipolar in character, the solar wind does not have to change the magnetic field configuration of the Sun. In a region of more complex polar structure, this is not true.

Schmidt: What fraction of the solar area would you ascribe to these coronal hole regions?

Newkirk: By looking at the X-ray pictures that have been published and in which the coronal holes are easily identifiable, I would guess 20–30%, excluding the poles.

Schmidt: Isn't it true that one needs an average field strength for the whole Sun of about 2 G to be in balance with the interplanetary magnetic field? Don't you need therefore to connect to some 80% of the quiet Sun – or, if you connect primarily only to the coronal holes, you need to connect some reasonable percentage of the field lines to high field areas, and this latter picture seems a little improbable.

R. Grant Athay (ed.), Chromospheric Fine Structure, 303–307.

Meyer: I think this is an important point that should be discussed.

Gabriel: Do you consider that the solar wind will have a higher velocity in these coronal hole regions?

Newkirk: The magnetic field allows the conductivity to carry the heat away more effectively. The scale height is higher in the coronal holes than it is in the rest of the regions where there is a restriction to the field. Even though the base temperature in the coronal holes may start out lower it decays less rapidly. Your question was, do I expect the velocity to be higher in the holes than elsewhere. Jerry Pneuman should answer that question but he is not here.

Smith: The answer to the question is yes, and that is consistent with observations. Art Hundhausen has shown that in fact the high-velocity winds observed in the solar stream are very well correlated with the coronal holes.

Gabriel: This seems to be contrary to the suggestion that Carole Jordan just made that the helium enhancement is consistent with higher solar wind velocities.

Jordan: Can I ask Dr Brueckner a question? Do you see the helium emission suppressed in the coronal holes?

Brueckner: Yes, the helium network is suppressed in the coronal holes, in the same way that it is over the poles.

Delache: I would direct a question to the one raised by Alan Gabriel. If the velocity of the wind is going to be larger in the coronal holes, what about the matter flux – is it larger or lower than in other regions?

Newkirk: It depends upon how much you ascribe to other regions. There is some question as to whether or not we have ever sampled any of the high-density regions that we see, in coronal streamers.

Delache: Let me put it in another way. If you observe a correlation between coronal holes and high velocities of the solar wind, what is the enhancement or the decrease of the mass flux?

Brandt: Mass flux is almost independent of speed, and statistically the high-velocity streams are associated with low density. The high-velocity streams generally have low density and high temperatures. The subject of the solar wind and coronal holes came up before in this symposium and I will make the statement again that I think it is premature to identify the coronal holes as the major course of the solar wind. There is simply too much evidence that demands a flow from a rather large fraction of the Sun.

Brueckner: I would like to raise a question about the identification of the coronal holes with high-velocity solar wind. On my last slide I showed the base of the coronal streamers as having intense helium network and not the suppressed helium network that we saw in the slides, at the location of the coronal holes.

Jordan: You see these little bright spots just at the bottom of the polar plumes as well, don't you?

Brueckner: This is still debatable, but always where we see a coronal streamer coming out we have an enhancement of the helium network.

Schmidt: I propose that we now discuss a little bit the question that has come up in a number of talks: how much of the magnetic flux coming out of the photosphere is going into the chromosphere and staying there, and how much goes on into the corona? There seems to be strong advocates for a large percentage of the flux staying in the chromosphere. The fibrils discussed by Dr Zirin and Dr Giovanelli and the MMF's discussed by Vrabec give independent evidences that there is a sizable percentage of flux staying in the chromosphere. On the other hand there is a serious problem with the Lorentz forces. If there is a sizable flux staying in the chromosphere, what we need is a flat-iron holding it down. This flat-iron has to have an exact weight which can be calculated. It comes out to be roughly 100 to 1000 times the total weight of the atmosphere available. We should discuss the possibilities for finding a solution to this problem. My own suggestion is that we consider a situation in which we have only a slight percentage – and I mean only 1 to 4% of the flux staying in the chromosphere and the rest going into the corona. This would be nearly a force-free situation. Certainly the fields of force are not force-free but they are nearly so. This raises the question as to how this can be reconciled with the evidence for field remaining in the chromosphere. The evidence boils down to a discussion of the radius of curvature of the fine structure in the chromosphere. This is very good evidence but I simply ask, is it not evidence that comes from a single very thin layer near 4000 km. Therefore I am tending to conclude that the radius vector of these curved features lies in the layer itself and not perpendicular to it. That is to say, we are dealing with spiral structures that lie at a level of 4000 km and a little bit deeper down. If so, we still have the question of what is the reason for the curvature. I would suggest that it is the very fact that about 60% of the flux in the regions where we see the spiral structure, that is near to the sources of the field, is leaving the region more nearly to the vertical than the angle subtended by the 4000 km height from half the diameter of the supergranule cell, which is a very small angle. That 60% of the flux which comes out, if you assume that the field is nearly force-free, has to go out somewhere between the fibrils that are so conspicuous. If so, I don't think that we have a serious problem with the spiral structure, because then we balance Lorentz forces against Lorentz forces. We do not have to balance them against the waves which are not there. We simply have flux lines which go out to large heights in the corona, and maybe to interplanetary space, which are as strong in their field strength as the surrounding fields intrinsic to the fibrils, but they have different curvature.

Zirin: I have two suggestions in regard to this very important question. In the filaments we have an example of a case where flux is confined very near the surface for very long distances, which in a potential type theory must – as Dr Schmidt has suggested – rise high above the surface. It is clear from observations by Foukal and others as inferred fields and by direct measurements of the magnetic field in prominences at the limb, that filaments exist wherever there is a magnetic boundary between one polarity and the other, where for long distances magnetic fields run parallel to the surface. In fact there we see a flat-iron, namely the material that occupies the filaments. This seems to be a very stable situation that lasts for a long time. There is no doubt that these lines of force in the filament are running parallel to the surface.

We are not talking much about the sharp curvature, but wouldn't you agree once again that you would not expect it to run parallel to the surface without having a flat-iron to hold it down.

The second point is that I think it is very important to determine just how high lines of force in substantial active regions go. It is my impression from studying my photographs – and I realize it is difficult to express this quantitatively – that the stronger the general connection between an active region with distant fields, the more sharply suppressed is the magnetic field underneath. In this case, the flat-iron seems to be the strong magnetic field between the active regions and the distant regions, which apparently keeps other fields from rising forward. It seems clear that the stronger the field, the more sharply the turning to the horizontal by the lines of force.

Schmidt: I accept your flat-iron with respect to any filament, be it active or quiescent. Certainly this is a small region visible on the disk where we have sufficient mass at a high elevation, suspended in the fields where exactly the magnetic tensions are balanced by the weight of the filaments. These cover a certain per cent of the active region, and I leave it to the observers to estimate that. I do not accept at all the other flat-iron you suggest. I did not mean that there has always to be an integral of the mass per cm^2 that balances the magnetic stresses. On the other hand, this does imply that at almost every point of the Sun the field is almost exactly vertical. There has to be some flux that stays within a scale height or two of 4000 km for a long distance, so that we can have correlated features visible in $H\alpha$ at that level. But we need only a tiny bit of the solar flux to account for that. Someone needs to look into this problem.

Dravins: I believe it is difficult to have only one or two per cent of the flux being in the chromosphere. This is because one can determine the magnetic field at different heights in plages and sunspots, and one can make an estimate as to how rapidly the magnetic structures in the network diverge with height. This gives consistent values in the sense that there is a distinct weakening of the longitudinal field with height which is because the field is bending over in the first few thousand kilometers, and on the inside of the network one sees the fibril type of structure. One doesn't see them down at the very bottom of the photosphere. If we believe that these structures follow the magnetic field, we can trace the field with height consistent with the observation that the field must have bent over quite sharply. It is difficult to estimate how much field will continue to remain at low heights, but if the fibril field does not remain at low heights then one must imply an additional kink in the field going through another bending upwards. Another comment – there is a problem with Lorentz forces coming from the magnetic kink in the chromosphere near active regions. It was mentioned yesterday that these moving magnetic features might be associated with magnetic field lines going up and down in the photosphere, and doing this in just a few thousand kilometers, in very strong fields. I think that in that type of field geometry the implied Lorentz forces are orders of magnitude stronger than the fields suggested by the Harveys.

Kiepenheuer: The fact that you observe the 4000 km altitude to consist of a very flat buttress for these fibrils, etc., does not mean that the field lines there are really at rest. As soon as these structures are lifted a little bit they will empty out and disappear by emptying out, so that there still could be flux above this level.

Deubner: My remark is similar to Dr Kiepenheuer's. So far as observations are concerned, I believe it is clear that the chromospheric fibrils tend to follow the average of the field direction but nobody so far has shown that indeed they follow the inclination of the field lines.

Vrabec: I suggest that a question of possible relevance is the interconnection of different active regions by magnetic flux tubes. Here perhaps the radio astronomers and X-ray astronomers can shed some light on the problems.

Miss Shahinay Yousef: I would like to ask Dr Newkirk if he thinks that the coronal holes are free from magnetic arches connecting distant active regions, and are the coronal holes related to the magnetic sector structure in the interplanetary magnetic field, or do they have something to do with the active regions?

Newkirk: I would ask Dr Altschuler to answer the first part of the question.

Altschuler: We generally find that coronal holes are associated with diverging fields. On the average the field is unipolar diverging outwards, but this is only in average conditions.

Schmidt: I wonder whether, at some future symposium, we might discuss the subject of possible dissipation in the chromosphere. At times we have talked about annihilation, at times about diamagnetic acceleration, at times we have talked about downward flow, or the need for it, and at other times we have talked about the transport of streams of mass into the corona by spicules and its return back to the chromosphere again. On the other hand we have both heard and seen beautiful evidence for dissipation in the chromosphere. We have seen brightenings at the borderlines of arch filament systems or eruptive flux regions; we have seen bright points of several kinds; and we have seen filigree. It would be very helpful if we would be able to ascribe mechanisms to the different observed phenomena.