GENERAL DISCUSSION

Statistics ...

WEIDEMANN: A comment on the distance scales for PN. If one introduces a scale factor, K, with the normalisation K = 1 for Seaton (1968), then one finds, for other distance scales: K = 0.8 (Acker), K = 1.5 (Cudworth), K = 1.04 (Daub), K = 1.3 (Weidemann), K = 1.3 (Jacoby), and K = 1.2 (Schneider et al., contributed paper at this meeting), giving PN birth rates, $1.3 \times 10^{-12} \lesssim \chi_{PN} \lesssim 14 \times 10^{-12}$ pc^{-3} y^{-1} (since $\chi_{PN} \propto K^{-4}$). As White Dwarfs probably do not all go through the PN stage, there remains a serious discrepancy with the White Dwarf birth rate ($\chi_{WD} \approx 1.5 \times 10^{-12}$ pc^{-3} y^{-1}) for $K \lesssim 1$.

JACOBY: The (1978) value of 10 000 PN in M 31 was derived before the luminosity function was observed. The newer data suggest that there are about 20 000 PN in M 31, corresponding to 10 000 - 15 000 in our Galaxy. This translates into K = 1.3 (compared with K = 1 for Cahn and Kaler), as suggested by Dr. Weidemann.

SERRANO: Do the scale heights of the low and high mass parts of the White Dwarf distribution differ? If so, could this explain the discrepancy with the PN scale height?

WEIDEMANN: The scale height of the White Dwarfs is larger than that of the PN, according to Green's Palomar study; but the mass distribution of the White Dwarfs is so narrow about the average (0.58 $M_\odot$) that it is not possible to determine the scale height as a function of the mass.

RENZINI: These discrepancies (in scale heights, statistics etc.) may arise as a consequence of the naive assumption that all PN have the same lifetime, irrespective of the initial mass of the parent star.

Formation of the nebulae ...

KAHN: We now have the picture in which the total mass in a PN is much larger than that seen in the form of ionized gas. This mass has been ejected by a slow superwind. Later, a fast (2 000 km s^{-1}) wind pushes this gas away from the central star and starts to compress it into a shell.

If the primary ejection was not spherically symmetrical, then the swept-up shell will show the same sort of angular dependence in density, but amplified. As far as I know, there is not yet a decent calculation of this effect, but it seems worth doing because there is a good chance that it will explain the origin of bipolar structures.

It is important, in this connection, that the ambient gas distribution (derived from the superwind) should extend to a large distance from the central star in all directions. There must be no chance of hot shocked gas escaping from the bubble through a hole in the jacket.

WANNIER: With regard to an asymmetric superwind, I wish to point out that, for the four circumstellar molecular clouds which we have mapped, there is no indication yet of a departure from circular symmetry. The symmetry is especially striking in IRC + 10 216, which has been

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extensively mapped, despite the indications of elongation in the inner infrared source.

HEAP: Before coming to this Symposium, I looked, with Allan Sweigart, at the question of rotation of Red Giant stars. If angular momentum is conserved, so that the core can spin up, then the outer edge of the core (i.e. the central star) of a Red Giant will rotate at 10 km s^{-1} if its initial mass was 1.5 $M_{\odot}$ and at 800 km s^{-1} if its initial mass was 3.5 $M_{\odot}$. So, perhaps rotationally enhanced ejection plays a role in the superwind.

PEIMBERT: If the core spins up, we should expect three phases in the mass loss process, the first being more or less spherically symmetric, the second with mass loss preferentially occurring close to the equatorial plane, and the third with confinement near the equator but not near the poles, owing to the presence of material ejected during the second phase. An object which shows evidence of these three phases is NGC 2440, which has an outer spherical halo, very faint and smooth, a bright ring or disk near the centre, and "lobes" or "ansae", presumably produced by the confinement of the disk.

RENZINI: Some White Dwarfs have strong magnetic fields, of the order of 10^3 gauss. When they were PN nuclei, their high speed (say, 3000 km s^{-1}) wind was probably very asymmetric, which may help in giving funny shapes to previously ejected, almost spherical shells.

KAHN: I disagree - it should be remembered that the fast wind gas is trapped in a bubble which is much larger than the linear dimensions of the inward facing shock. It does not really matter, in such a case, how the fast wind leaves the central star. All that happens to it is that it contributes thermal energy to the hot shocked wind bubble, which will expand quite subsonically and will not be affected particularly by the way in which the gas is injected.

NUSSBAUMER: In my suggestion about the origin of PN (1982, Astron. Astrophys. 110, L1), I gave a mass loss formula $\dot{M} \propto B^2$. About 5 - 10% of White Dwarfs have $10^4 \lesssim B \lesssim 10^5$ gauss. Fields lower than 10^3 gauss could not, at present, be detected, but, in analogy to the Sun, the mean magnetic field may be the result of magnetic flux tubes of much higher local field strengths. Under such conditions, magnetic fields would dominate all other pressure terms and could easily produce mass loss. The same remark applies to Red Giants, where convection could produce locally strong emerging magnetic flux. Thus, I think that magnetic fields could, at certain stages in the evolution towards and during the PN stage, be of fundamental importance.

ZUCKERMAN: Regarding the comparison between symbiotic stars and PN, it is interesting to note that, in the former case, we (very probably) have a close binary star but relatively little mass ejection (as judged from infrared and radio observations), whereas PN contain much more ejected mass but show little evidence for close binary central stars. This seems difficult to reconcile with a picture in which mass ejection in PN is supposed to be enhanced by the presence of a close companion.

TERZIAN: A very small percentage (perhaps about 1%) of known PN have binary stars. There should be many more, since more than one half of the field stars are in binary stellar systems. Perhaps we should intensify our searches for binary PN nuclei.

KEYES: It should be remembered that there are two broad classes of symbiotic stars: those with infrared (dust) emission (D-type), and those without (S-type). The D-type symbiotics are radio sources, and it has been suggested that they are proto-PN. The S-type symbiotics include all known symbiotic binaries but only one radio source, AG Peg; this is the only S-type symbiotic that we can definitely say contains a subdwarf (see my contributed paper, this volume). It has been suggested that super-critical wind accretion on a disk about a main sequence star may supply the ionizing photons that produce the observed emission spectrum. This might also account for the lack of radio emission from S-types, since there would be no mass lost from the system to produce it.

A further, interesting aspect of symbiotics is that the observed emission line spectra of some of them resemble those of Seyfert galaxies. Several symbiotics display a wide range of ionization (up to [Fe VII]) and composite emission line profiles (both narrow and broad components). Electron temperatures and densities in these symbiotics are similar to those in the Seyferts. Therefore, the symbiotics provide a nearby and much brighter laboratory in which to study plasmas that are similar in some respects to those found in Seyferts and QSO's.

Characteristics of the central stars ...

HEAP: This morning, Pottasch showed us two displays of the mass distribution of the central stars of PN. The distribution in the L/T_{eff} (HR) diagram implied a median mass well under 0.6 $M_\odot$, whereas the distribution in the M_V/R_{neb} ("Schönberner") diagram implies a median mass of 0.6 $M_\odot$. The same distance scale was used in both diagrams, so what is the reason for the discrepancy?

POTTASCH: In the diagram of M_V against the age of the nebulae, as deduced from the ionized size and expansion velocity, the points extend very far to the left of the diagram. If the ages of these nebulae were correct, they would indicate that the central stars must have very high mass indeed. The difficulty in interpreting this diagram is that optically thick nebulae should not be placed on it. This is because the ionized mass may be much smaller than the total mass and, consequently, the derived age is much too low. I think that most of the nebulae whose derived ages are less than 3-4 x 10^3 y are optically thick and should be removed from the diagram. This is why it seems preferable to use the HR diagram, where all nebulae can be represented.

KALER: When interpreting results (temperatures, luminosities etc.) obtained for the central stars, it should be remembered that we still have poor data on magnitudes and expansion velocities for many objects.

ALLER: The question of the temperatures of PN nuclei is fundamental, and we must explain the discrepancies that occur. The energy distribution of the central star that is required to model the spectrum of the nebula often corresponds to a much lower temperature than proposed by Pottasch, at least for a number of the hottest objects. The stellar temperatures which we derive from nebular models tend to be in harmony with those suggested by Seaton.

HUMMER: If the effect that Abbott and I have obtained in the one model (contribution to second poster session, this volume) is anything like universal, then the He II continuum becomes closer to a blackbody at the effective temperature of the star. This would have the consequence that the He II Zanstra temperatures have a more nearly universal meaning as blackbody temperatures.

SEATON: Two different approaches to the determination of central star temperatures and luminosities have been presented, by Schönberner and Weidemann, on the one hand, and by Pottasch, on the other. The former obtain distances assuming the nebulae to be optically thin and plot absolute visual magnitudes against nebular radii. The latter uses individual distances (the accuracy of which might, in many cases, be questioned) and plots nebular masses against electron densities. From this work, it is concluded that most nebulae are optically thick.

In neither case is much of an attempt made to estimate the optical thickness of individual nebulae, although this can be done (by comparing H I and He II Zanstra temperatures, or the presence of outer halos, for example).

Dust in PN ...

HOUCK: I think that there is strong evidence for a considerable amount of dust inside the ionized gas of many PN. For example, the 12 μm "photo" of NGC 7027, shown by Terzian, follows the "free-free" radio contours (the nearest strong fine-structure line is [Ne II] 12.8μm).

BARLOW: The depletion of the C IV resonance lines, observed in several PN, definitely implies the presence of dust inside the ionized region. However, no more than $\tau_D \approx 0.1$ is required to explain the observations. Shields has shown that gas-phase iron and some other heavy elements are heavily depleted in PN. If these elements were locked up in grains which had a reasonable size distribution, they could give rise to $\tau_D \approx 0.1$.

If a significant amount of carbon was tied up in grains, the dust optical depth could be embarrassingly large. I believe that the C/O ratio derived from observations of gas-phase carbon correctly reflects the total carbon abundance.

SEATON: The total thermal infra-red emission is a significant fraction (say, 10 - 20%) of the total energy emitted by many PN. One can understand how the dust is heated if it is inside the ionized region. I think that the problem is made more difficult if the dust is assumed to be outside the ionized region.

KWOK: There is no doubt that there is dust outside - the question is, what is the temperature of this dust?

PEIMBERT: It should be added that the observations of Aitken and Roche definitely show that the unidentified features arise outside the ionized zone in NGC 7027.