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*TWO INTERESTING NUCLEI OF PLANETARY NEBULAE: IC 418 AND NGC 40**

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Attention has recently been directed by several investigators to the possible relation between Bethe's[1] process of energy generation and the chemical branching among the Wolf-Rayet shells and among the atmospheres of late-type stars. However the connection, if there is any, is not yet clear; hence it is important to collect additional observational material concerning the behavior of carbon and nitrogen in cosmic sources. Toward this end work was started at the McDonald Observatory in 1939. The program consisted of objects of high excitation: O stars (especially those of class Of, with vestiges of emission), Wolf-Rayet stars and planetary nuclei.

The subdivision of the Wolf-Rayet stars into a carbon sequence and a nitrogen sequence has been investigated in detail by C. S. Beals,[2] who has found that the split holds for all observed objects which are not surrounded by visible nebulosity. The subdivision may be readily extended to the absorption O stars with vestiges of emission. For example, in the case of 9 Sagittae and HD 192639, which resemble one another in their absorption spectra, the former shows strong N III and weak C III emission lines, whereas the opposite is true for the latter.

Until quite recently it had usually been assumed that the nuclei of planetary nebulae, when of the Wolf-Rayet type, also belonged to one of the two sequences. But actually, since most planetary nuclei are very faint, the assignment to one of the two branches was often doubtful. Among the objects on our observing program were NGC 6543 and Campbell's hydrogen envelope star (BD +30°3639). The nucleus of NGC 6543 had been tentatively classified as a *WN*6 star by Beals,[3] whereas C. H. Payne had placed it among the carbon stars.[4] Our spectrograms show conclusively that the characteristic lines of N IV, C IV and O IV appear with similar intensities,[5] so that the object is intermediate between the *WN* and *WC* sequences. An investigation of IC 4997[6] showed that the nucleus of this stellar planetary also possesses lines of N III, C III and C IV and is, thus, of a type similar to NGC 6543 but of lower excitation. The investigation of BD 30°3639[7] called attention to the rather striking association of a pure carbon nucleus surrounded by a nebulosity rich in nitrogen. In the nucleus of BD 30°3639 there is no trace of nitrogen at any stage of ionization, whereas the red color of the nebular envelope is due to [N II] at least as much as to H_α. Another object, HD 167362, was found spectroscopically[8] to be exactly of the same type, although its distance is too great to allow the nebula to be resolved.

We have now investigated two other planetaries: IC 418, whose nucleus shows bright lines of N III, and C III with similar intensities, and NGC 40, which has a pure *WC* nucleus surrounded by a nebulosity rich in nitrogen.

IC 418.—The nucleus was tentatively classified as *WC*7 by Beals,[3] whereas C. H. Payne[4] considered it as a star without carbon. Several spectrograms were secured in January, 1941, at the McDonald Observatory. We also had the privilege of using an excellent spectrogram taken by Dr. E. Hubble at the Mount Wilson Observatory. Nothing important could be added to the descriptions of the nebular spectrum by Wright[9] and by Stoy.[10] The red lines of [N II] are very strong, their combined intensity being similar to the intensity of H_α; [N II] 5755 is also fairly strong. But our spectrograms of the nucleus reveal more detail than had formerly been observed. The region from λ 4500 to λ 4700 is especially interesting: strong nuclear, fairly sharp lines of N III (λλ 4634.16 and 4640.64) and of C III (λλ 4647.40 and 4650.16–4651.35; λ 4665.90) are present. Other nuclear lines due to carbon or nitrogen are observed at λ 4267 (C II), λ 4325 (C III), λ 5696 (C III, strong) and λ 4058 (N IV, trace).[11] These bright lines have widths of about 2.35 A (or 155 km./sec.) at λ 4640; their radial velocity is identical with the value obtained for the nebula.

The behavior of He II is similar to that in 9 Sagittae, as is also the absence of O III in emission.[12] All the He II lines, except λ 4686, appear as wide absorptions ($\Delta\lambda$ = 5.7 A at λ 4542 or Δv = 370 km./sec.); λλ 5412, 4542 and 4200 are fairly strong; the other members of the $4f\ ^2F^\circ\text{–}ng\ ^2G$ series appear as wide absorptions unsymmetrically underlying the bright, sharp Balmer lines. Bright λ 4686 is sharper than the absorption lines; its width is approximately 4.5 A (or 285 km./sec.); its radial velocity is identical with the values derived from the absorption lines and from the nebular emissions. Hence, λ 4686 is emitted in a symmetrical shell while λλ 5412, 4542, 4200, etc., are absorbed in the reversing layer of the underlying star. The excitation of bright λ 4686 must be of similar origin as in

9 Sagittae and in similar objects. It is probably due to the absorption of Lyman α by the He^{+}-ions in the metastable $2s\ ^2S$-level.

On the other hand, this nucleus differs radically from 9 Sag in that it shows strong carbon lines. The emission is also more marked than in 9 Sag, as compared to the absorption.

We conclude that the nucleus of IC 418 is an O-type star with a strong continuous spectrum upon which are superposed emissions of C III, N III, C II and He II 4686, but which presents the series of $4f\ ^2F^{\circ}$–$ng\ ^2G$ of He II in absorption. The bright lines are narrower than in pure Wolf-Rayet stars or in 9 Sag; the widths of the N III and C III lines correspond to an ejection velocity of the order of only 80 km./sec. This is the lowest velocity of ejection which we have observed for an object which is similar to Wolf-Rayet stars.[13]

NGC 40.—The nucleus has a typical Wolf-Rayet spectrum, very similar to that of the nucleus of BD 30°3639. It was classified as a *WC*-star, both by Beals and by Payne[14] on the basis of Wright's observations. Our spectrograms show that nitrogen is absent or extremely weak, compared to carbon. The visual region was not described by Wright, but our spectrograms reveal so complete a similarity to BD 30°3639 that a separate description of NGC 40 is not necessary. The nebular spectrum had not been observed in the visual region. Our spectrograms show that the red [N II] lines are present, with a combined intensity similar to that of H_{α}.

The object is analogous to Campbell's star or to HD 167362 and consists of a pure *WC*8 nucleus surrounded by a nebulosity which is rich in nitrogen.

Other Planetary Nuclei.—A list of tentative classifications of planetary nuclei has been published by Beals. It includes thirteen nuclei, among which nine are considered as *WC* stars and four as *WN* stars. Among the nine nebulae with a carbon nucleus, four had been observed in the red region and all show strong [N II] lines. The present paper shows that one of these nine objects, IC 418, contains both C and N and that its surrounding nebulosity contains also nitrogen. The four nuclei classified by Beals as *WN* objects are: NGC 6543, NGC 6572, NGC 6826 and IC 5217. For NGC 6543 our material shows beyond any doubt[5] that the nucleus contains both C and N; the nebulosity shows also fairly strong [N II] lines despite its high excitation; permitted lines of carbon appear also in the nebula. The spectrum of IC 5217 is not sufficiently well known and requires further observations. For the nuclei of NGC 6572 and NGC 6826, excellent descriptions have been published by Wright. In the nucleus of NGC 6572, the characteristic lines λλ 4634–4641 of N III, λ 4650 of C III, λλ 4659 and 5802–5812 of C IV are present. Hence, the simultaneous presence of C and N is certain. In the nucleus of NGC

6826, Wright observed a broad band extending from λ 4635 to λ 4661; it is presumably a blend of the characteristic N III, C III and C IV lines.

To these objects listed by Beals, we should now add IC 4997, whose nucleus contains both C and N, and HD 167362 which is similar to Campbell's object.

Conclusions.—The planetary nuclei exhibiting bright features belong to two classes:

(*a*) Nuclei of the *WC* type, showing no trace of nitrogen. In all cases where the visual region of the nebular spectrum has been observed, the forbidden lines of [N II] are strong in the surrounding nebulosity. Typical examples are BD 30°3639, NGC 40, HD 167362.

(*b*) Stars showing with similar intensities lines of C and N. In those cases where the visual spectrum has been observed, the nebulosity exhibits [N II]. In one case which has been investigated in detail—NGC 6543—relatively strong permitted lines of C II and C III appear in the nebula. Typical examples are NGC 6543, IC 418, IC 4997, NGC 6572.

To our knowledge no planetary nucleus of Wolf-Rayet type can at present be attributed to the nitrogen sequence. The only exception may be the nucleus of NGC 2392, in which Wright[9] observed bright N III lines and in which we also found weak N V.[12] But this star is essentially an absorption O-type star of the 9 Sagittae type and the emission is not the essential feature.

These characteristics of the planetary nuclei should be compared to those of Wolf-Rayet stars without visible nebulosity. Among the latter there are no intermediate cases between the *WN* and *WC* sequences and the numbers of *WN* and *WC* objects are practically the same. Beals[2] has already called attention to a possible difference between the mean radii of the Wolf-Rayet planetary nuclei and those of the ordinary Wolf-Rayet stars.

In all cases of planetaries which have been observed in the red region, the [N II] lines are present, even if the nucleus is a pure carbon star. This fact is probably of some cosmological importance.

* IC 418 (HD 35914; BD −12°1172); α (1900) $5^h22^m.8$; δ (1900) −12°46′ NG.C 40 (HD 826); α (1900) $T0^h7^m.6$; δ (1900) +71°58′.

[1] *Phys. Rev.*, **55**, 434 (1939).

[2] For example: *Jour. Royal Astr. Soc. Canada*, **34**, 169 (1940).

[3] *Pub. Dom. Ap. Obs., Victoria*, **4**, 286 (1930).

[4] *Zs. f. Ap.*, **7**, 1 (1933).

[5] *Ap. Jour.*, **92**, 289 (1940).

[6] *Ap. Jour.*, **93**, 356 (1941).

[7] *Proc. Nat. Acad. Sci.*, **26**, 548 (1940)

[8] *Proc. Nat. Acad. Sci.*, **26**, 454 (1940).

[9] *Lick Obs. Pub.*, **13**, 193 (1918).

[10] *Lick Obs., Bull.*, **17**, 179 (1935).

[11] There is an unidentified line at λ 4571, also observed in various other high excitation objects. This line probably belongs to the nebula.

[12] *Ap. Jour.*, **91**, 546 (1940).

[13] *Ap. Jour.*, **93**, 354 (1941).

[14] But C. H. Payne includes N III and N IV among the constituents of the spectrum.

RADIOACTIVE CARBON AS AN INDICATOR OF CARBON DIOXIDE UTILIZATION. V. STUDIES ON THE PROPIONIC ACID BACTERIA

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Previous studies[1,2,3] on CO_2 uptake by the propionic acid bacteria using labeled CO_2 have shown that the two major products of the glycerol fermentation, propionic and succinic acids, contain labeled carbon. The succinic acid has been shown to contain C* only in the carboxyl groups.[2] The results of preliminary experiments using short-lived radioactive carbon (C^{11}) led to the suggestion that the labeled carbon was present in the C_2H_5-group as well as the carboxyl of the propionic acid.[3]

Further experiments have shown this suggestion to be incorrect. The mechanisms of the reactions used to locate the C* in the propionic acid have been investigated. On the basis of the information so obtained the propionic acid formed by the bacteria during a glycerol fermentation in the presence of C^*O_2 has been shown beyond any reasonable doubt to *contain C* only in the carboxyl group.*

The previous experiments on the location of C* in the propionic acid were carried out by means of an alkaline permanganate oxidation. The products are carbonate and oxalate[4] and the reaction follows almost quantitatively the equation

$$\begin{array}{l} CH_3 \\ | \\ CH_2 \\ | \\ COO^- \end{array} + 4MnO_4^- = \begin{array}{l} COO^- \\ | \\ COO^- \end{array} + CO_3^{=} + 4MnO_2 + OH^- + 2H_2O \qquad (1)$$

The oxidation was effected by alkaline $KMnO_4$, at 100°C. for varying lengths of time with the addition of one gram of inactive propionic acid to act as carrier. The excess MnO_4^- was carefully reduced with H_2O_2