THE LINEAR POLARIZATION OF RADIO SOURCES BETWEEN 11 AND 20 CM WAVELENGTH

II.* POLARIZATION AND RELATED PROPERTIES OF EXTRAGALACTIC SOURCES

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Summary

The polarization properties of quasars, radio galaxies, and unidentified objects at 11 and 20 cm wavelength are discussed and compared with other source characteristics. For some quasars, scintillation and spectral data are in accord with current ideas that the sources comprise a small component radiating only at high frequencies and a larger component with a radiation spectrum similar to radio galaxies. The polarization is associated with this second component. For radio galaxies, the lower polarization of scintillators and a decrease of luminosity with increasing polarization suggest that sources of high brightness have low polarization. In spectral and polarization characteristics, the unidentified sources are similar to radio galaxies. Source evolution is discussed; the results suggest that quasars and radio galaxies evolve separately rather than represent different stages of a single evolutionary sequence.

I. INTRODUCTION

In the first of three papers concerned with observations of linear polarization of radio sources (Part I, present issue pp. 79–106) the polarization results of 366 sources at 11, 18, and 20 cm have been tabulated, together with associated radio and optical data. In the present paper an analysis primarily of the polarization data at 11 and 20 cm is given, but without any consideration of Faraday rotation effects within the Galaxy, which will be covered in the third paper (Gardner, Morris, and Whiteoak, unpublished data).

There have been a number of suggested correlations between polarization and various other source parameters; results up to the end of 1965 have been reviewed by Gardner and Whiteoak (1966). Now, with an increased number of optical identifications, which permits the division of the sources into different classes, and with more extensive data it is possible to test with greater statistical certainty the significance of the correlations. Some general radio properties of quasars, radio galaxies, and unidentified objects for the sources in the survey are first discussed at some length before proceeding to polarization. A useful criterion of source structure is scintillation behaviour, and in the analyses sources are divided into scintillators and non-scintillators for investigating relationships with angular size.

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II. Significance Test

A simple method for testing the significance of correlations which is used extensively throughout this paper is the 2×2 chi-squared test. If a total of $(a+b+c+d)$ quantities in an x, y distribution is such that for divisions at x_1, y_1 the following occurs

	$x < x_1$	$x \geqslant x_1$
$y < y_1$	a	b
$y \geqslant y_1$	c	d

then $\chi^2 = (a+b+c+d)(ad-bc)^2/\{(a+b)(c+d)(a+c)(b+d)\}$. With the calculated value of χ, the probability ϵ that the relationship between a, b, c, and d could arise by chance is read from Table III of Fisher (1958) for one degree of freedom. The correlation will be accepted as significant in the following discussions if ϵ is less than $0 \cdot 05$.

III. Characteristics of Source Sample

(*a*) *Selection*

The sources observed for polarization were selected mainly from the Parkes catalogue (Bolton, Gardner, and Mackey 1964; Day *et al.* 1965; Price and Milne 1965; Shimmins *et al.* 1966), in which the basic survey was effected at 75 cm to a limiting flux density between 3 and 4 f.u. In general, polarization observations were made of those sources whose flux densities exceeded either 2·5 f.u. at 20 cm or 1·5 f.u. at 11 cm. Additional sources from other catalogues for regions not covered at Parkes, e.g. near the galactic plane, were selected on the same basis. Bolton (1966), in order to obtain maximum homogeneity in an analysis of optical identifications, limited his investigations to an area well away from the galactic plane and its associated optical obscuration and between declinations $-33°$ and $+20°$, where the radio data were statistically most complete. For the purpose of comparison between identified and unidentified objects in the present analysis, only sources in this region are considered. Of the observed extragalactic sources the area contains 54 of the 64 quasars, 79 of the 114 radio galaxies, and 50 of the 148 unidentified objects. The galaxies include five "normal" spiral galaxies, which are excluded from the group in all subsequent discussion.

(*b*) *Scintillations*

For sources that can be observed when the solar elongation is less than 50°, scintillation due to the interplanetary medium indicates the presence of source structure with angular extent smaller than 1″ (Hewish, Scott, and Wills 1964). Scintillation data are available for about 40% of the sources under discussion. Most were obtained at Parkes from observation at 2·2 m wavelength (Whiteoak, unpublished data); the remainder resulted from limited observations at shorter wavelengths and from the scintillation investigation carried out by Cohen, Gundermann, and Harris (1967). If a source is observed to scintillate, it may generally be assumed that at least 30% of its total intensity at 2 m wavelength emanates from a region around 0″·3 or less in angular extent. It is believed that most non-scintillating sources were sufficiently intense at 2 m wavelength for a negative result to be physically significant. Scintillations for sources with flat spectra and insufficient intensity for observations at 2 m were detected at the shorter wavelengths. Within the restricted zone 29 of the 46 quasars scintillate (63%), 15 of the 67 radio galaxies scintillate (22%), and 17 of the 39 unidentified sources scintillate (43%).

Scintillation effects occur in 3 out of 44 cases (7%) for all radio galaxies brighter than 17 mag. and in 13 out of 41 cases (32%) for galaxies of 17 mag. and fainter. Therefore, on the average, scintillation of radio galaxies appears to be associated with a decreasing mean angular size due to increasing distance. Since the range of observed

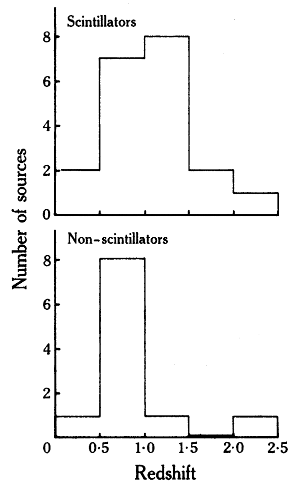

Fig. 1.—Redshift histograms of scintillating and non-scintillating quasars.

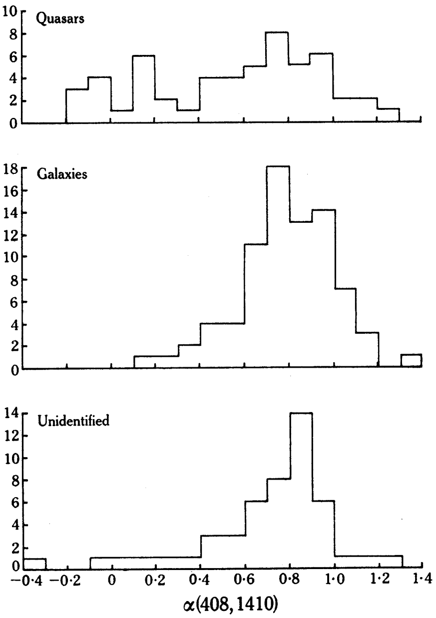

Fig. 2.—Histograms of spectral index $\alpha(408, 1410)$ for quasars, radio galaxies, and unidentified sources in the Bolton zone.

radio flux is small, scintillators are the sources of higher brightness. There is some variation with morphological galaxy type, since scintillation occurs for 42% of N-type galaxies, 7% of D-type galaxies, and 14% of galaxies of types E and SO, for similar intervals of apparent magnitude.

Histograms of the redshifts of scintillating and non-scintillating quasars are shown in Figure 1. A possible explanation of the higher median redshift for the scintillators is a decrease in mean angular size with distance if the redshifts are cosmological. A more likely explanation is discussed in the following subsection. The scintillation statistics for the quasars together with the trend for radio galaxies support the conclusion of Bolton (1966) that the unidentified sources are mainly galaxies beyond the magnitude limits of the Palomar Sky Survey.

(c) *Spectral Indices and Spectral Curvature*

In Part I the spectral index α (defined by the relation flux density $\propto$ (frequency)$^{-\alpha}$) applies to the spectral range 408 to 1410 MHz. The curvature C given by $\alpha(1410, 2650) - \alpha(408, 1410)$ is positive for a source with a spectrum that steepens with frequency (on a log{intensity}–log{frequency} basis). The data at 408 MHz were mostly derived from Parkes catalogues, whereas the flux densities at the higher frequencies were measured during the polarization observations. Integrated flux densities were determined for those sources known to be moderately extended in order that α and C might be independent of resolution effects. No spectral index was computed for greatly extended objects.

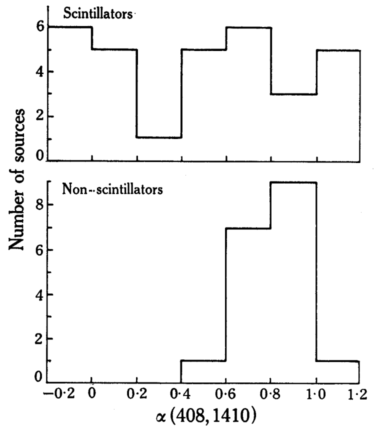

Fig. 3.—Histograms of spectral index $\alpha(408, 1410)$ for all scintillating and non-scintillating quasars.

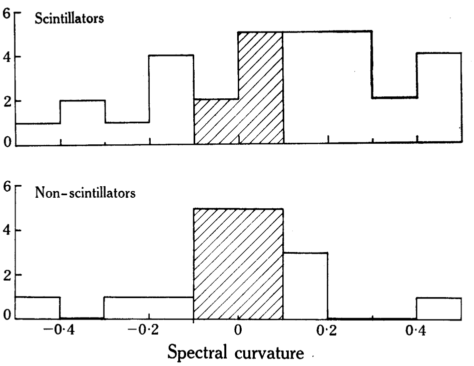

Fig. 4.—Histograms of spectral curvature for scintillating and non-scintillating quasars. A comparison of the populations of the hatched zones relative to those outside the zones is described in the text.

Histograms of the spectral indices for quasars, galaxies, and unidentified sources are shown in Figure 2. They support the more comprehensive data of Bolton (1966) for which spectral indices were based on the frequencies 1410 and 2650 MHz. For quasars, the wider histogram is due to a higher proportion of objects with flat or negatively curved spectra. The similarity of the histograms for galaxies and unidentified sources is additional support for the view, given previously by Bolton (1966), that the latter are mostly optically faint galaxies.

Separate spectral index histograms for all scintillating and non-scintillating quasars are shown in Figure 3. While the results for non-scintillators are similar to those for galaxies, it appears that all objects with flat spectra scintillate. Since the flat-spectrum objects are relatively weak at low frequencies where the scintillation observations were made, experimental selection would produce the opposite of the observed effect. If a division is made at $\alpha = 0 \cdot 6$, the disparity is significant at the $0 \cdot 1\%$ level. Several conclusions can be drawn from the figures. The flatness of the spectra of some quasars has been interpreted (Pauliny-Toth and Kellermann 1966; Harris 1967) as due to the existence of two components of radiation. One component is similar to the radiation from radio galaxies, while the other occurs at high frequencies, vanishing at low frequencies as a result of synchrotron self-absorption. Since all sources of flat spectral type scintillate, it may be inferred that the high frequency component is of small angular size. On the other hand, quasars of steep spectral type (i.e. spectral indices similar to the non-scintillators), and possibly those regions of "flat" quasars which radiate the low frequency component, have a considerable range of angular size. At face value, the higher median redshifts for scintillators in Figure 1 could be due to a decrease in angular size of "steep" quasars with distance on the assumption of a cosmological redshift. However, Figure 5 of Bolton (1966) shows that the median redshift of "flat" sources exceeds that of the "steep" sources as a consequence of the higher intrinsic luminosities of the flat-spectrum quasars. This feature also prevails for the sample of quasars in the present discussion and is the main reason for the difference in the median values of Figure 1.

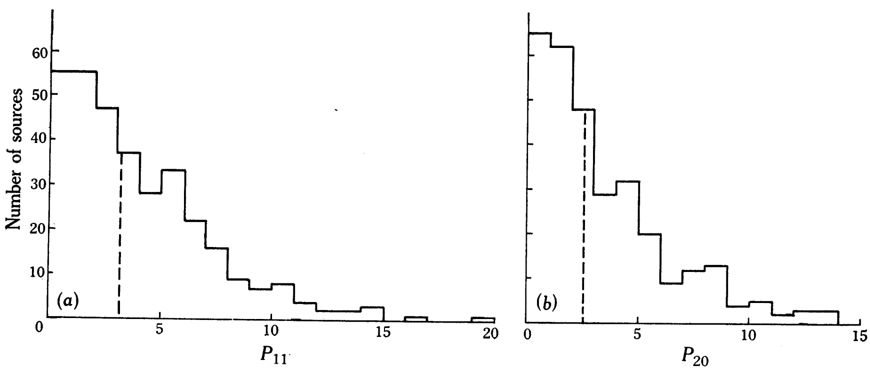

Fig. 5.—Histograms of polarization at (*a*) 11 and (*b*) 20 cm for all observed extragalactic sources. The dashed lines show the median values.

Histograms of spectral curvature for quasars are shown in Figure 4. For the other groups of sources the range of spectral curvature is small and possibly the result of experimental errors. The dispersion is greater for scintillators, the median is $+0\cdot04$ and quartile width $0\cdot39$; for non-scintillators the median is $+0\cdot03$ and quartile width $0\cdot15$. If the number of sources with curvature $-0\cdot1 \leqslant C < 0\cdot1$ (hatched zones in Fig. 4) is compared with the number outside this range, the difference between the scintillators and non-scintillators is significant at the $1\cdot5\%$ level. Both spectral types of quasar contribute to the larger dispersion of the scintillating group.

With regard to the relationship between spectral curvature and redshift for quasars, no correlation exists for the non-scintillating group. There is a suggestion of an increase of curvature with redshift for the scintillators which is significant, however, only at the 7% level for divisions at $C = 0\cdot0$, $z = 0\cdot9$.

IV. Polarization Characteristics

Figure 5 consists of histograms of percentage polarization at 11 cm (P_{11}) and 20 cm (P_{20}) for all sources. The median values are $3\cdot2\%$ and $2\cdot6\%$ respectively. The histogram of the polarization ratio $D = P_{20}/P_{11}$ for these observations is shown in Figure 6. The median value is $0 \cdot 8$, close to the value given by the ratio of the two polarization medians. While D would be a measure of depolarization if it resulted merely from Faraday depolarization, with the degree of polarization of each emitting element the same at both wavelengths, the fact that D exceeds unity for a considerable fraction of the sources indicates that dispersion in rotation depths (Gardner and Whiteoak 1966) is not the only factor involved. For several cases Morris and Whiteoak (1968*b*) found that where $D > 1 \cdot 0$ the sources consisted of multiple components with different spectral indices, and it was suggested that the observed effect is due to the association of the polarization predominantly with the low frequency components.

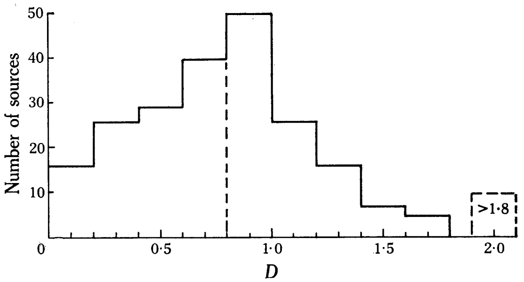

Fig. 6.—Histogram of polarization ratio D. The median value is shown by the dashed line.

(*a*) *The Polarization–Luminosity Relationship*

A relationship between polarization and luminosity of radio galaxies is suggested by the fact that the extended low-luminosity objects have the highest polarization. In the search for such a relation approximate distances were derived from redshift data when available, using a Hubble constant of 100 km sec^{-1} Mpc^{-1}, or from apparent magnitudes on the assumption of a constant absolute magnitude. As the sources considered are well away from the galactic plane, a constant reddening correction was applied to the magnitudes. It was determined by means of galaxies for which both magnitude and redshift data are available. In such cases, despite the possibility of large individual errors due to the inclusion of magnitudes estimated from prints of the Palomar Sky Survey, or due to differential reddening, the dispersion in the relation between magnitude and redshifts is less than half a magnitude. However, individual cases such as PKS 1836+17 (3C 386) have considerably greater differences.

Figure 7 shows the logarithm of absolute radio luminosity L_r ($= 4\pi d^2 S$, where S is the flux density and d the distance) plotted against P_{11}. It shows the expected drop in median luminosity with increasing polarization. The double galaxies (db) do not show the trend; there is no obvious explanation for this behaviour unless the close coupling of two individual galaxies results in twisted or chaotic magnetic fields. With such galaxies excluded, the significance level is $0 \cdot 2\%$ for a division at $P_{11} = 8\%$, $\log L_r = 18 \cdot 5$. Because of the small range of apparent radio magnitude (approximately 50% of the sources have flux densities between $1 \cdot 5$ and $2 \cdot 5$ f.u. at 11 cm), selection favours high luminosity sources and discriminates against those of low luminosity. With a sample in which the intrinsic luminosity distribution has the same limits at each distance, a steeper slope than that shown would be expected.

The effect shown by Figure 7 was first pointed out by Gardner and Whiteoak (1962). It is probably due to an increasing disorder in a radio source with absolute luminosity and not to depolarization in extragalactic space. In support of this conclusion, a $\log L_r$ versus D plot (not shown) shows no significant change of median D with L_r. However, a feature of such a distribution is the almost complete restriction of sources with $D > 1 \cdot 0$ to $L_r > 18 \cdot 0$ (the correlation for divisions at these positions is significant at the $2 \cdot 5\%$ level). An explanation is difficult—it may be due in part to the exclusion of many high luminosity sources because of low polarization at 11 cm, or it may indicate that the intrinsically luminous sources have multiple structure (with the spectral indices and polarization differing from one region to another).

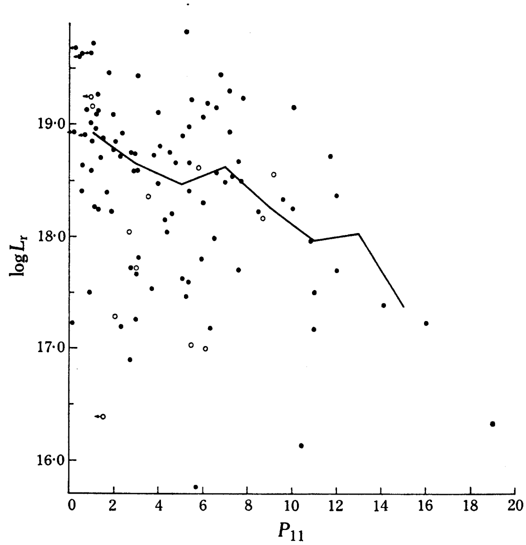

Fig. 7.—Relationship between 11 cm polarization P_{11} and log(radio luminosity) $\log L_r$ for radio galaxies. Double galaxies (type db) are represented by open circles. Median values of $\log L_r$ are joined by the solid line.

Figure 8 consists of polarization histograms at 11 cm of the sources in the Bolton zone. The median values are $3 \cdot 5$, $3 \cdot 3$, and $2 \cdot 6\%$ for the quasars, galaxies, and unidentified sources respectively. The normal spiral galaxies, not included in the sample, have very low values of P_{11}; radio galaxies of type SO and E have the highest values. The groupings are shown divided into scintillating and non-scintillating sources. The median polarization and population (in parentheses) of each subgroup are listed in Table 1. For the scintillating sources, the median polarization decreases progressively from quasars through galaxies to unidentified objects. The difference in the medians of scintillators and non-scintillators is insignificant for quasars. However, for a sample division at $P_{11} = 6\%$ the difference is significant at the $0 \cdot 5\%$ level for galaxies and at the $0 \cdot 1\%$ level for unidentified objects. In addition, a unique feature of the histogram for non-scintillating galaxies is a double peaked distribution; it might indicate the presence of two populations. For the galaxies, since those that scintillate have higher brightness, the results support the conclusions of the previous section that the more luminous a galaxy the lower the polarization (on the average, sources of highest radio brightness have the highest luminosity). More important, they indicate that the unidentified scintillating sources are galaxies of even higher brightness. Although the median for the unidentified non-scintillating sources is close to that for the quasars, conclusions cited previously suggest that the group consists predominantly of galaxies with lower brightness than scintillators but with more luminosity and therefore lower polarization than their optically identified counterparts.

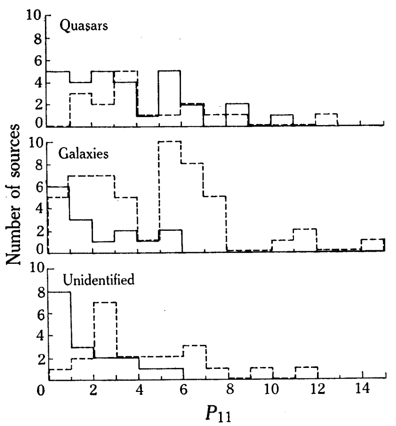

Fig. 8.—Histograms of 11 cm polarization P_{11} for quasars, radio galaxies, and unidentified objects in the Bolton zone:
—— Scintillating sources,
- - - Non-scintillating sources.

Table 1

MEDIAN PERCENTAGE POLARIZATION OF DIFFERENT SUBGROUPS

Populations are shown in parentheses

Sources	Quasars	Galaxies	Unidentified
Scintillators	3·1 (29)	1·5 (15)	1·2 (17)
Non-scintillators	3·7 (17)	5·1 (52)	3·5 (22)
Total	3·5 (59)	3·3 (76)	2·6 (49)

(*b*) *Polarization–Spectral Index*

The relationship between polarization and spectral index was investigated, but the only trend found was a weak tendency for a polarization decrease with spectral index increase for radio galaxies.

Only for the galaxies is there an indication of a variation in the median value of the polarization ratio D (P_{20}/P_{11}) with spectral index (Fig. 9(*a*)). The decrease in D with increasing spectral index may have several causes. For objects with flat spectra, due possibly to source structure (such as core–halo) where physical conditions vary from component to component, the polarization radiation may have a steep spectrum in contrast to the flat spectrum of the unpolarized radiation. Objects with the steepest spectra may suffer internal depolarization caused by high magnetic fields.

Although quasars are devoid of any relationship between polarization ratio and $\alpha(408, 1410)$, the scintillators show a well-defined trend when $\alpha(1410, 2650)$ is used (Fig. 9(*b*)). For division at $D = 0 \cdot 5, \alpha = 0 \cdot 5$ the correlation is significant at the 1% level. One obvious conclusion is that the radiation from the high frequency

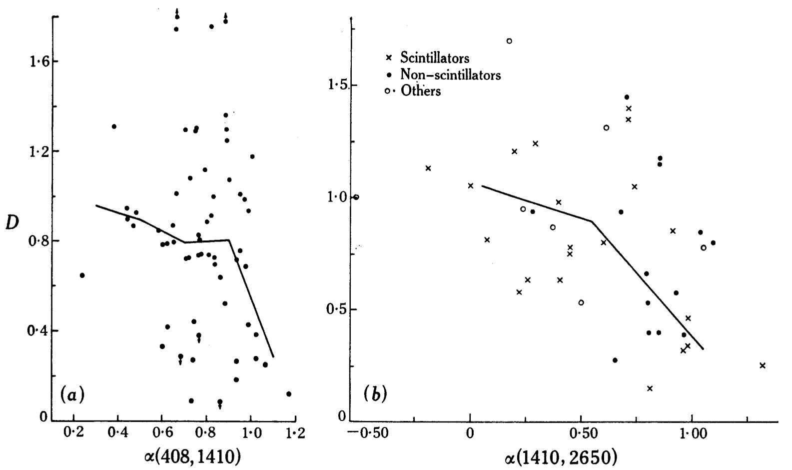

Fig. 9.—Variation of polarization ratio D with (a) spectral index $\alpha(408, 1410)$ for radio galaxies and (b) spectral index $\alpha(1410, 2650)$ for quasars. Trends in median values of D are shown by the solid lines (only for scintillating sources in (b)).

component generally becomes prominent between 1410 and 2650 MHz, and the polarization between these frequencies is dependent on $\alpha(1410, 2650)$, but not on $\alpha(408, 1410)$. In addition, the increase of D with decreasing α is consistent with most of the polarization being associated with the low frequency component.

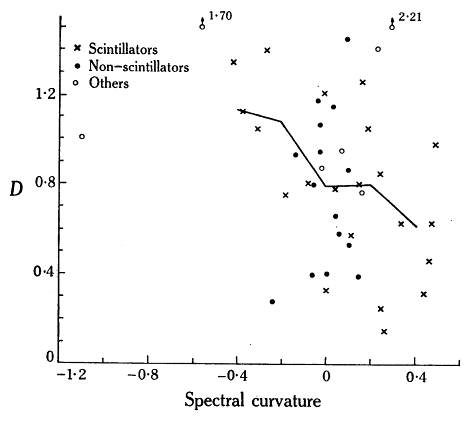

Fig. 10.—Variation of polarization ratio D with spectral curvature for quasars. Median values for scintillating sources are joined by the solid line.

(c) *Polarization–Spectral Curvature*

Because of the small range of values of spectral curvature C for galaxies and unidentified objects, and the influence of errors in its determination, the parameter has significance for quasars only. Plots of C against the polarizations P_{11} and P_{20} result only in scatter diagrams. However, the polarization ratio D plotted against C for scintillating quasars (Fig. 10) shows a decrease with increasing curvature. The correlation is significant at the 3% level for divisions at $C = 0 \cdot 0$, $D = 0 \cdot 8$, and is probably due to the presence of the high frequency data in the curvature parameter.

(*d*) *Polarization–Redshifts for Quasars*

No relationship is evident between the polarizations P_{11} and P_{20} and redshifts for non-scintillating quasars, but for the scintillators low values of polarization ratio D were found to be weakly associated with high redshifts (the trend is only significant at the 7% level with divisions at $D = 0{\cdot}8$, $z = 1{\cdot}0$).

(*e*) *Intrinsic Polarization and Structure of Radio Galaxies*

The distribution of the difference between the intrinsic direction of polarization and the position angle of source elongation is shown in Figure 11(*a*). This is an up-to-date version of Figure 13 in the review given by Gardner and Whiteoak (1966) except that only a single average value is given for sources resolved into separate

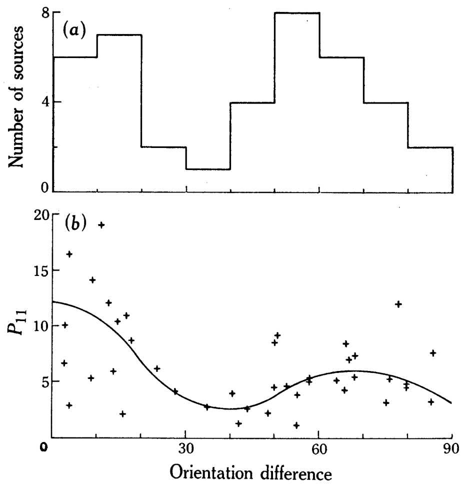

Fig. 11.—Showing the orientation difference, i.e. the difference between the intrinsic direction of polarization and the position angle of source elongation, (*a*) as a histogram for radio galaxies and (*b*) plotted against the 11 cm polarization P_{11} for the sources included in (*a*).

components. The maximum near the orientation difference 0° is still prominent, but the second peak is now near 60°. As pointed out previously, objects of high brightness (i.e. high luminosity on the average) have large orientation differences. The minimum at 90° may be due to the fact that since these objects have low polarization it has not been possible to determine their intrinsic angles of polarization. The distribution therefore still supports the evolutionary theory advanced by Gardner and Whiteoak (1966). Additional support comes from the distribution of polarization P_{11} with orientation difference (Fig. 11(*b*)). The feature of the plot is the minimum in the distribution at around 40°. In the model proposed by Gardner and Whiteoak (1966) the polarization should drop nearly to zero when the "flip" from orientation difference 90° to 0° occurs. However, it should be emphasized that the observations provide only the integrated polarization; recent interferometric studies of polarization (Seielstad 1967; Morris and Whiteoak 1968*a*) show that the polarization distribution generally cannot be interpreted in terms of a simple model. It is in fact surprising that the observations represent the most characteristic polarization features with such accuracy as to provide the general trends that have been discussed.

(*f*) *Direction of Polarization–Wavelength Relationships*

Gardner and Whiteoak (1963) first suggested that Faraday rotation relations (the variation of polarization angle with (wavelength)^2) were in general linear and due predominantly to the magnetoionic medium of our Galaxy. In addition, some sources have nonlinear Faraday rotation relationships. This may occur with quasars where the high and low frequency components of radiation are polarized in different directions (see Morris and Whiteoak 1968*b*) or with extended radio galaxies such as PKS 1717−00 (Morris and Whiteoak 1968*a*) in which differential internal Faraday rotation may exist from one component to the other. Since data were taken at only two or three frequencies, it is beyond the scope of the present discussion to analyse this feature in detail, as it requires observations over a greater frequency range.

V. Discussion

(*a*) *Evolution of Radio Sources*

Various attempts have been made to fit radio sources with widely differing parameters into an evolutionary sequence. In a log(luminosity)–(log(brightness) diagram, Heeschen (1966) shows that most of the radio galaxies define a broad line having a slope of around unity which at its high luminosity end intersects a horizontal line formed by the quasars. Heeschen suggests that the lines are "evolutionary tracks or the loci of evolutionary tracks". The first explanation is also implied in the investigations of Simon and Drake (1967) and Ryle and Longair (1967); the latter used the component separation from the parent galaxy to relate luminosity to age. Their interpretation is that quasars evolve from high brightness objects by expansion with fixed luminosity until they become radio galaxies, after which they follow the line with unity slope (i.e. evolution with radius constant). In actual fact, the slope of the radio galaxy curve in Heeschen's plot exceeds 1·0, which suggests that the source would be contracting in size with age. However, the slope becomes unity if the southern sources Cen A (PKS 1322−42·8, 1322−42·7), For A (PKS 0319−37, 0322−37), and MSH 13−3*3* (PKS 1332−33, 1333−33, 1334−33) are added, and 3C 386 (PKS 1836+17), which has anomalous luminosity, is removed from the plot.

The existence of a single evolutionary sequence can be criticized on several counts. Since the average degree of polarization of quasars is independent of brightness, it is difficult to see why the polarization should remain constant over the quasar path then drop virtually to zero at the point of intersection with the radio galaxy branch. The intersection of the radio galaxy and quasar branches seems to occur near the magnitude limit of the Palomar Sky Survey for galaxies, and it is a matter of conjecture whether this contributes to the abrupt termination of the galaxy branch. The path of evolution does not include normal galaxies, nor does it contain the radio galaxies such as M82, 3C 120 (PKS 0430+05), and 3C 71 (PKS 0240−00), which are young objects on present ideas of evolution and which are located to the right of the radio galaxy sequence.

Heeschen's alternative appears more probable. In this, there is no restriction on the luminosity that the original explosion may attain. The source would originate in a region of high brightness in the diagram (but not necessarily in the region of high luminosity) and in the initial stages of expansion its brightness decreases rapidly, while its luminosity remains constant or perhaps even increases if the original object had a high optical depth. In the vicinity of the present radio galaxy branch, expansion is being slowed down by the stretching of the magnetic field or by the intergalactic medium, the emissivity is decreasing owing to energy losses by radiation, and the locus of evolution is downwards with a slope that progressively approaches unity. At this point the external and internal pressures are equal. In this fashion the presence of young sources to the right of the branch are explained. The position of a source on the radio galaxy branch tells nothing about the stage of evolution except that it is proceeding at a nearly constant radius. Support for this sequence of evolution comes from Cen A and MSH 13−3*3*, sources containing a central component and outer regions. The outer regions are located in the diagram to the left of the area defining the radio galaxy branch, while the inner, presumably younger, regions are situated to the right of the area. The evolution is also in keeping with spectral index behaviour. It is reasonable to expect a spectrum to steepen with time, and in fact Kellermann (1964) has added observational support by finding an increase in spectral index with component separation. Kellermann has also suggested that spectral index tends to be greater for high luminosity galaxies, which is contrary to a single evolutionary sequence as discussed in the initial part of this section.

The preferred evolution is in accord with the polarization behaviour, namely, the change from the 90° to the 0° orientation difference accompanying the fall in brightness. The 0° difference, when expansion is restricted by the intergalactic medium, is probably only attained by the less luminous galaxies, since with the more energetic explosions in the high luminosity source, this configuration may only be reached when the source is beyond the limit of detectability. For the brighter objects, a greater disorder in magnetic field configurations is expected, resulting in low polarization and internal Faraday depolarization. These high luminosity objects could cause the hitherto unexplained polarization minimum at the 90° orientation difference in Figure 11(*b*). The presence of fine-scale structure and internal depolarization provides a mechanism for the production of the reported polarization ratio greater than unity with such sources. The sources associated with normal galaxies, objects of low luminosity, also have low polarization, and these objects may represent young objects at the other end of the luminosity spectrum.

A quasar might begin as a small, compact, and highly luminous source of optical depth sufficiently high to restrict the radiation to high frequencies. Owing to the high optical depth or very symmetrical magnetic fields, the radiation is virtually unpolarized. The source expands anisotropically, the decreasing optical depth permits radiation at lower frequencies, there is a decrease in the emission at the highest frequencies, and the magnetic fields become sufficiently aligned to yield a net integrated polarization. The source finally becomes a non-scintillating quasar. Before the stage of evolution with constant radius is reached, the flux density may have fallen below the level of detection. For some cases the procedure may be repeated and such quasars (of flat spectral type) comprise a young and unpolarized component and an evolved but polarized component.

(*b*) *General Properties of Quasars*

Throughout the discussion the sample of quasars has been divided into two groups according to angular size, namely scintillators or non-scintillators. The non-scintillating sources have spectral indices similar to galaxies and show little spectral curvature. On the other hand, many of the scintillating objects have flatter spectra than the non-scintillators and appreciable range of spectral curvature. The discussions have indicated that the division in terms of angular size is for the most part a division in linear size rather than a distance effect for objects of similar linear size. For the sources of flat spectral type the results support the theoretical models comprising a region of low frequency radiation plus a young compact region of high frequency emission. The objects of normal spectral index have single radiating regions with a large range of size. The steep spectral indices of some scintillators can be explained in terms of a single small component of steep spectral type, with or without another component of flatter spectral type.

For sources with multiple components of radiation, the synchrotron cutoff of the high frequency emission and the intensity of emission are known to vary from source to source and also with time (Kellermann and Pauliny-Toth 1968). Therefore, it is not surprising that there is no general relationship between spectral index and curvature or redshift, or that there exists a barely significant variation of median curvature with redshift. Polarization does not correlate with spectral index, curvature, or redshift, although in individual cases it is known to be associated with the low frequency component. The polarization ratio is a parameter that is independent of the polarization at one frequency and should correlate better with the models. The correlation with curvature is significant, but the weak relationship with redshift occurs presumably because of the curvature–redshift result. In contrast to the negative relationship with the spectral region 408–1410 MHz, the most significant correlation occurs with the spectral index between 1410 and 2650 MHz, and it is probably this parameter that gives the curvature its significance in the correlation.

VI. References

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