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ABSOLUTE MAGNITUDES OF E AND S0 GALAXIES IN THE VIRGO AND COMA CLUSTERS AS A FUNCTION OF $U - B$ COLOR

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ABSTRACT

Three-color photoelectric data are listed for 25 galaxies in the Coma cluster and six faint dwarf ellipticals in the Virgo cluster. The correlation between standard isophotal apparent magnitude of the galaxies and their $U - B$ values has a correlation coefficient of $r = 0.94$, and extends over 8.5 magnitudes. The rms deviation of the $U - B$ correlation gives $\sigma(\Delta V_{26}) = 0.72$ mag, excluding the two largest residuals.

K-corrections are computed and listed for $U - B$ and Q indices for $z \lesssim 0.03$. Applying the corrections to the Coma cluster permits the color-magnitude effect in Coma and Virgo to be compared, so as to test the zero-point difference between the clusters. The least-squares magnitude shift between Coma and Virgo is $\Delta V_{26} = 3.66 \pm 0.14$ mag from the color-magnitude effect, agreeing with $\Delta V_{26} = 3.84$ ($+0.42$, -0.36) required by the ratio of the redshifts, if there is no local shear to the velocity field at Virgo. The present data are inconsistent with the Abell and Eastmond hypothesis of fitting humps in the luminosity function that requires $\Delta V = 4.7$ mag.

The need for a second parameter in the $M_v = f(U - B)$ relation is uncertain.

The color-magnitude relation is expected to be useful in estimating relative distances to field E and S0 galaxies on the scale of the distance to the Coma cluster.

I. INTRODUCTION

Indications that giant and dwarf elliptical galaxies have different energy distributions were available from Stebbins and Whitford's (1952) two-color measurements of bright galaxies. Their C_P colors of NGC 147, 185, 205, M32, and especially of the dwarf ellipticals near M100 (NGC 4321) are bluer than the average giant elliptical.

Baum (1959) discussed the effect in $B - V$, and extended the correlation to globular clusters. Code (1959, fig. 3) showed that Whitford's spectrum-scan of M32 is much bluer shortward of λ4000 Å than the giant E galaxy NGC 4374. De Vaucouleurs (1961*a*, fig. 4) discussed the relation in $U - B$ and $B - V$ for Virgo Cluster E and S0 galaxies. McClure and van den Bergh (1968) correlated the parameter Q with apparent magnitude for Virgo cluster galaxies; Rood (1969) compared data on the Coma and Virgo clusters; and Lasker (1970) showed the generality of the effect by his narrow-band measurements of E and S0 galaxies in groups.

The work reported here, done in the 1961 observing season, is concerned with *UBV* photometry of galaxies in the Virgo and Coma clusters. The data were obtained to test the color-magnitude effect in two groups of galaxies at different redshifts. Does a common relation exist that is shifted in apparent magnitude by the difference in the distance modulus of the clusters, as determined from the ratio of the redshifts?

The galaxies that were observed in the Coma cluster ranged from NGC 4889 (the brightest) to the faintest that could be conveniently measured in the U passband with the 200-inch (508 cm) telescope in reasonable integration times without blind offsets. The range spanned 5 mag into the cluster. These data and the measurements of six dwarf ellipticals in the Virgo cluster are listed in this paper. A comparison of the color-magnitude effect over a range of 8 mag is given in the next several sections.

If the correlation is a one-parameter relation, it would provide the means to estimate the absolute magnitude, and hence distance, of E and S0 galaxies once their $U - B$ or Q values are measured. The method would have promise to map more accurately any local anisotropy to the galaxian velocity field (de Vaucouleurs 1958*a*). Study of the generality of the relation with this in mind requires additional data on other groups and clusters, but in this paper we are concerned only with the effect itself, and with its calibration in units of the Coma cluster distance.

II. THE DATA

The observations were made with the 200-inch prime-focus photometer using an RCA 1P21 photomultiplier, a General Radio d.c. amplifier, and a strip-chart recorder. The galaxies that were measured in Coma were E and S0 types as determined by inspection of direct plates taken at the prime-focus for classification purposes. The photoelectric observations were made with several aperture sizes to test for radial color gradients, and to correct for aperture effect to a standard isophotal magnitude.

The results are listed in table 1, where the galaxies are named either by their NGC, IC, or numbers assigned by Rood and Baum (1967, hereafter called RB). The classification of galaxy type determined by RB is listed in column (2). Column (3) gives the diameter of the photometer aperture in arc sec, and column (4) is the ratio of this diameter to the major axis tabulated by RB.

The photometry was calibrated for extinction and for transformation to the standard system by observing an average of 15 secondary *UBV* standards per night, spread well in sec z and color. The internal accuracy of the data should be $\lesssim \pm 0.02$ mag (rms) for all colors and magnitudes.

In addition to the galaxies of the Coma cluster, six of the many dwarf ellipticals in the Virgo cluster (Reaves 1956) were observed. A particularly interesting concentration of these surrounds NGC 4321 (M100), which is one of the bright spirals in the region. Figure 1 is a reproduction of a 48-inch (122 cm) Schmidt photograph centered on M100, taken with a $2\frac{1}{2}$-hour exposure on Eastman IIIaJ emulsion that was baked at 65° C for 8 hours, and developed for 11 minutes in MWP2 (Difley 1968). The dwarf systems that were measured are numbered, and the data are listed at the end of table 1.[1]

III. THE COLOR-MAGNITUDE CORRELATION

Data for some of the bright Virgo cluster ellipticals have been listed by de Vaucouleurs (1961*a*, tables 2 and 7). They range in magnitude from the brightest members to the intermediate dwarf IC 3475 at $V_T \simeq 13.5$. To this limit, the correlation of V_T with $U - B$ and $B - U$ has been discussed by de Vaucouleurs (1961*a*, fig. 14), and the correlation of the reddening-free parameter $Q = U - B - 0.72\ (B - V)$ was made by McClure and van den Bergh (1968).

These relations can now be extended to a limit 3 mag fainter with the data for the M100 dwarfs in table 1, and a new analysis of all material was made after testing for a radial color gradient (de Vaucouleurs 1961*a*, fig. 9; Hodge 1963).

Plots of $U - B = f(A/D)$ were made from table 1. Although a general trend is present, in the sense that $U - B$ becomes bluer as A/D increases, a substantial number of galaxies do not follow the sense of the average (cf. Hodge 1963, figs. 1 and 2), which has a slope of $\Delta(U - B)/\Delta(A/D) \simeq 0.03$ mag. Rather than correct each galaxy to a standard A/D by this ratio, we adopt the mean values of $U - B$ and $B - V$ from table 1. The procedure gives results that only rarely differed by more than 0.02 mag from a statistical reduction to $A/D = 1.0$.

The relevant data are summarized in table 2. Isophotal visual magnitudes, corrected

[1] I have lost the 1961 finding chart that contained the working numbers for the galaxies. Although an attempt has been made to connect the numbers in figure 1 and table 1 correctly, an error may still exist. It is certain that the six galaxies marked are those that were measured, but several of the numbers may be permuted.

TABLE 1

UBV PHOTOMETRY OF 26 COMA CLUSTER GALAXIES AND 6 DWARF ELLIPTICALS NEAR M100 IN THE VIRGO CLUSTER

NAME	TYPE	A(sec)	A/D	V	B - V	U - B
N 4873	SO	7.62	0.41	15.49	1.04	0.47
		12.19	0.66	15.06	1.01	0.53
		18.80	1.02	14.76	0.98	0.63
		30.60	1.65	14.52	0.98	0.93
N 4874	SO	12.19	0.35	14.29	1.09	0.55
		18.80	0.54	13.81	1.08	0.54
		30.60	0.88	13.37	1.05	0.53
		48.3	1.39	12.97	1.04	0.50
		24.4S	0.70	13.56	1.12	0.44
		41.5S	1.19	13.10	1.07	0.48
		41.5S	1.19	13.02	1.07	0.44
		68.6S	1.97	12.54	1.09	-
RB 37	SBO	12.19	1.23	17.12	0.95	0.27
		18.80	1.90	16.93	0.96	0.30
RB 38	SO	12.19	0.71	16.40	0.87	0.48
		18.80	1.10	15.96	1.03	0.39
RB 40	SO	12.19	0.76	15.97	0.96	0.33
		18.80	1.18	15.64	0.96	0.33
		30.60	1.91	15.25	0.93	0.31
RB 42	SO	12.19	0.80	16.23	1.01	0.35
		18.80	1.24	15.97	0.90	0.22
		30.60	2.01	15.47	0.93	0.20
RB 45	EO	12.19	1.26	15.66	0.98	0.42
		18.80	1.94	15.47	0.98	0.44
		30.60	3.15	15.34	0.97	0.38
RB 46	SO	12.19	0.82	16.03	0.94	0.30
		18.80	1.26	15.84	0.91	0.24
		30.60	2.05	15.62	0.95	0.25
IC 3998	SBO	7.62	0.32	15.81	1.05	0.41
		18.80	0.79	15.12	1.02	0.36
		30.60	1.28	14.91	1.00	0.35
RB 59	SO	18.80	2.19	16.71	0.99	0.50
N 4883	SBO	12.19	0.53	15.02	1.04	0.44
		18.80	0.81	14.72	1.07	0.40
		30.60	1.32	14.54	1.04	0.46
RB 51		12.19	2.97	17.21	0.84	0.33
		18.80	4.58	16.90	0.95	0.20
RB 71	EO	12.19	4.88	17.64	0.89	0.30
N 4881	EO	18.80	0.79	14.36	1.03	0.48
		30.60	1.29	14.08	1.03	0.49
		48.3	2.03	13.86	1.04	0.43
N 4886	EO	12.19	0.73	14.96	0.98	0.39
		18.80	1.13	14.66	0.94	0.36
		30.60	1.84	14.31	0.94	0.44
RB 74	SO	12.19	0.69	16.37	0.89	0.19
		18.80	1.06	16.11	0.86	0.25
		30.60	1.73	15.88	0.88	0.25
IC 4011	EO	12.19	1.00	15.59	0.96	0.37
		18.80	1.54	15.35	0.98	0.30
		30.60	2.51	15.22	1.01	0.33
IC 4012	E3	18.80	1.58	15.05	1.03	0.47
		30.60	2.57	14.98	1.04	0.47
		48.3	4.06	14.98	1.04	0.49
N 4889	E4	12.19	0.27	13.62	1.07	0.57
		18.80	0.41	13.19	1.06	0.56
		30.60	0.67	12.80	1.06	0.55
		48.3	1.05	12.46	1.05	0.52
RB 85	SO	18.80	4.00	17.20	0.86	0.27
		30.60	6.51	17.00	0.98	0.34
IC 4021	EO	18.80	1.69	15.17	0.98	0.44
		30.60	2.76	15.08	0.97	0.40
IC 4026	SBO	18.80	0.97	15.13	0.99	0.32
		30.60	1.58	14.92	0.96	0.32
		48.3	2.49	14.78	0.93	0.37
N 4906	E3	12.19	0.61	15.04	1.01	0.46
		18.80	0.94	14.76	1.00	0.41
		30.60	1.54	14.55	0.97	0.40
IC 4042	SBO	12.19	0.45	14.94	1.03	0.44
		18.80	0.69	14.71	1.01	0.44
		30.60	1.13	14.47	1.02	0.42
N 4921	SBb	12.19	0.14	14.70	1.03	0.51
		18.80	0.22	14.36	1.02	0.53
		30.60	0.35	13.98	1.03	0.49
		48.3	0.56	13.58	1.00	0.49
N 4923	EO	12.19	0.49	14.64	1.00	0.37
		30.60	1.22	14.12	0.99	0.46
		48.3	1.93	13.95	0.96	0.36
		M100 DWARFS (VIRGO)				
M 100,1	dE	18.80	0.41	15.61	0.78	0.22
		30.60	0.67	15.02	0.76	—
M 100,2	dE	18.80	0.70	16.93	0.72	0.09
M 100,3	dE	18.80	0.57	16.57	0.77	0.07
		30.60	0.93	16.24	0.74	0.12
M 100,4	dE	30.60	0.66	15.42	0.79	0.32
M 100,5	dE	18.80	0.47	15.11	0.82	0.20
		48.3	1.20	14.12	0.81	0.20
M 100,6	dE	18.80	1.45	17.19	0.45	-0.15

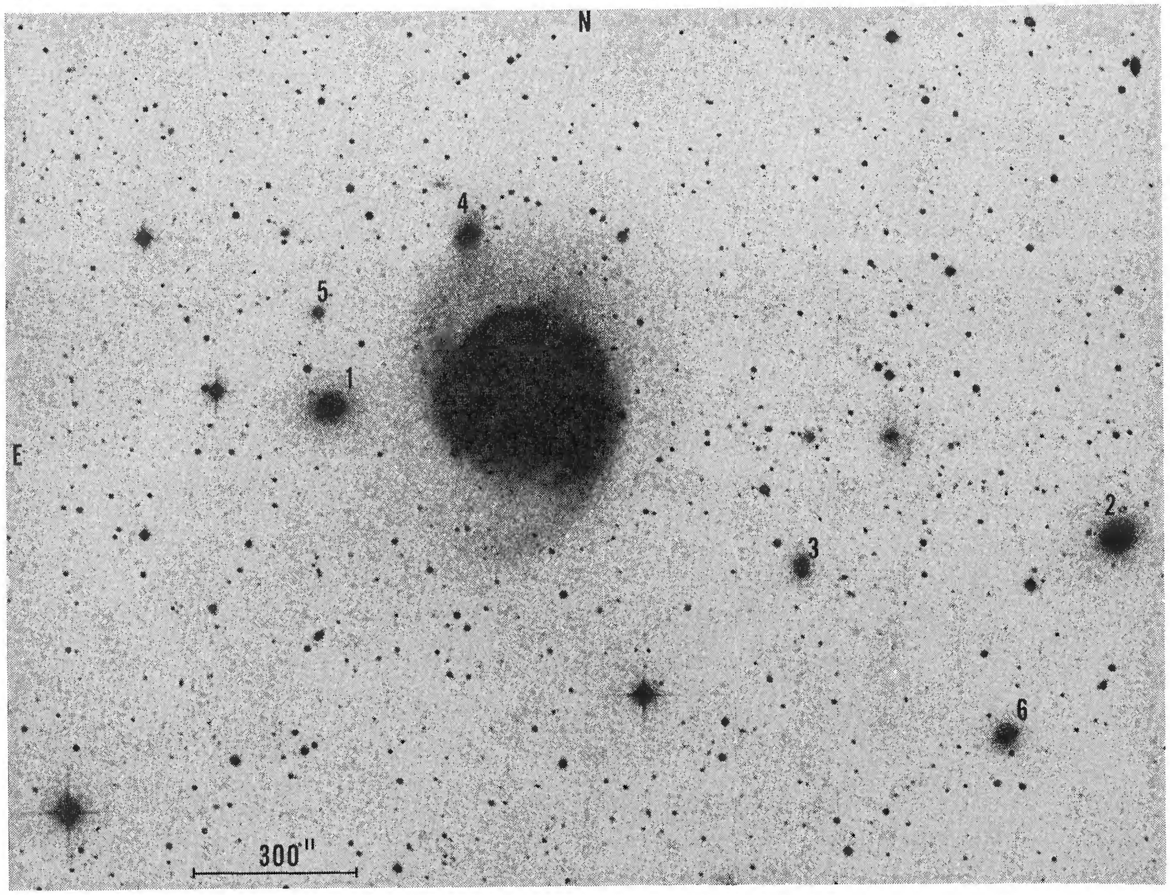

FIG. 1.—Portion of a IIIaJ plate taken near NGC 4321 (M100) in the Virgo cluster with the Palomar 48-inch Schmidt showing the six dwarf ellipticals listed in table 1. There are many fainter dwarf ellipticals in this general region of the Virgo cluster.

to the level of 26 mag per square second of arc, are listed as V_{26} in column (2) as taken from Holmberg (H, 1958), de Vaucouleurs (V, 1961*b*), Humason, Mayall, and Sandage (HMS, 1956), or estimated here (S) from the data in table 1 as corrected by a standard growth curve (HMS, Appendix A).

Plots of both $U - B$ and Q versus V_{26} show a remarkably well defined relation that extends from $V_{26} = 8.5$ to $V_{26} = 17.0$. For Virgo cluster data alone, the impartial least-squares line for the $U - B$ correlation has the form

$$V_{26} = -12.50(U - B) + 16.69 , \qquad (1)$$

which is the mean of the two equations that treat, in turn, V_{26} and $U - B$ as the independent variable. The correlation coefficient for the 19 Virgo cluster galaxies is $r = 0.94$. Individual residuals from equation (1) give $\sigma(\Delta V_{26}) = 0.95$ mag.

A similar correlation of V_{26} with Q for Virgo cluster data (excluding M100, No. 4) gives

$$V_{26} = -20.28Q + 6.73 , \qquad (2)$$

where $\sigma(\Delta V_{26}) = 1.05$ mag, and the correlation coefficient is $r = 0.92$.

Qualitatively, equations (1) and (2) show that the trends established by de Vaucouleurs, and by McClure and van den Bergh, extend to the present fainter limit, and are mono-

TABLE 2

MEAN PHOTOMETRIC PARAMETERS FOR GALAXIES IN TABLE 1 AND IN THE VIRGO CLUSTER*

Name	V_{26}	$\langle U-B\rangle$	$\langle B-V\rangle$	Q	Name	V_{26}	$\langle U-B\rangle$	$\langle B-V\rangle$	Q
				Virgo Cluster					
N4168.....	11.39(H)	0.40	0.98	−0.30	N4486.....	8.74	0.58	0.97	−0.12
N4374.....	9.36(H)	0.59	0.99	−0.12	N4643.....	10.5(V)	0.56	0.97	−0.14
N4406.....	9.25(H)	0.54	0.92	−0.12	I3475......	13.8(H)	0.13	0.67	−0.35
N4435.....	11.03(H)	0.49	0.90	−0.15					
N4438.....	10.20(H)	0.47	0.97	−0.23	M100, 1...	14.6(S)	0.22	0.77	−0.33
N4458.....	12.0(V)	0.36	0.86	−0.26	M100, 2...	16.5(S)	0.09	0.72	−0.43
N4461.....	11.06(HMS)	0.53	0.94	−0.15	M100, 3...	15.9(S)	0.10	0.76	−0.45
N4472.....	8.49(H)	0.64	0.97	−0.06	M100, 4...	15.0(S)	0.32	0.79	−0.25
N4476.....	12.4(V)	0.27	0.86	−0.35	M100, 5...	13.9(S)	0.20	0.82	−0.39
N4478.....	11.4(HMS)	0.34	0.94	−0.34	M100, 6...	17.0(S)	−0.15	0.45	−0.47
				Coma Cluster					
N4874.....	12.4	0.53	1.07	−0.24	N4886.....	14.4	0.40	0.95	−0.28
RB37.....	17.0	0.28	0.96	−0.41	RB74.....	16.0	0.23	0.88	−0.40
RB38.....	15.9	0.44	0.95	−0.24	I4011.....	15.3	0.33	0.98	−0.38
RB40.....	15.8	0.32	0.95	−0.36	I4012.....	15.0	0.48	1.04	−0.27
RB42.....	16.0	0.26	0.95	−0.42	N4889.....	11.8	0.55	1.06	−0.21
RB45.....	15.4	0.41	0.98	−0.30	RB85.....	17.4	0.31	0.92	−0.35
RB46.....	15.8	0.26	0.93	−0.41	I4021.....	15.1	0.42	0.97	−0.28
I3998.....	15.0	0.37	1.02	−0.36	I4026.....	14.9	0.34	0.96	−0.35
RB59.....	16.7	0.50	0.99	−0.21	N4906.....	14.5	0.42	0.99	−0.29
N4883.....	14.5	0.43	1.05	−0.33	I4042.....	14.4	0.43	1.02	−0.30
RB51.....	17.1	0.26	0.90	−0.39	N4921.....	12.8	0.51	1.02	−0.22
RB71.....	17.5	0.30	0.89	−0.34	N4923.....	14.1	0.40	0.98	−0.30
N4881.....	13.8	0.47	1.03	−0.27					

* Observed values are tabulated. To correct to zero redshift, Coma cluster values must be made redder in $U-B$ by 0.03 mag, bluer in $B-V$ by 0.06 mag, and more positive in Q by 0.08 mag.

tonic with no (or at most only a weak) plateau of constant color at the bright end, in contrast to the correlation in $B-V$ (Baum 1959).

But the main importance of the new material concerns the generality of the color-magnitude relation from cluster to cluster. A comparison of equations (1) and (2) with the data on the Coma cluster is useful for two questions. (*a*) Are the slope-coefficients of the equations the same from cluster to cluster? (*b*) If all galaxies were to follow the same relation (that is, if there is no second parameter), then the zero points of equations (1) and (2) should differ between Virgo and Coma by the difference in the distance modulus. Is this the case?

The slopes of equations (1) and (2) are so steep that systematic errors ± 0.01 mag in $U-B$ or in Q will cause errors of 0.1 and 0.2 mag, respectively, in the modulus-difference test. Hence, before question (*b*) can be answered, the effect of redshifts on $U-B$ and on Q must be determined.

IV. K-CORRECTIONS IN $U-B$ AND Q FOR REDSHIFTS LESS THAN 9000 KILOMETERS PER SECOND

Numerical integration of the mean energy distribution of giant E galaxies (Whitford 1971, table 2 for 36-inch [91 cm]), when folded with the natural transmission functions u_1, and b_1 (Matthews and Sandage 1963, Appendix A with eq. [A9]), gives calculated $U - B$ colors at zero redshift. The procedure, if repeated by numerically redshifting Whitford's standard curve through the u and b filters using $\lambda_{new} = \lambda_0 (1 + z)$, gives $\Delta(U - B) \equiv f(z)$. The same procedure in $B - V$ gives $K_{B-V} = f(z)$, as for example in Whitford (1971, table 3) or Schild and Oke (1971, table 3). From these, $K_Q = f(z)$ can be obtained by appropriately combining K_{U-B} and K_{B-V}.

The required $U - B$ integrations were performed here for discrete redshift values of 0.00, 0.01, 0.02, and 0.03. Curiously, because of the nature of the precipitous drop in $I(\lambda)$ shortward of $\lambda \simeq 4000$ Å, the $U - B$ color becomes bluer under redshift for $z \lesssim 0.03$, contrary to the well-known monotonic reddening in $B - V$ and $V - R$.

The results of these calculations are shown in table 3, where the sign convention is such that the tabulated $\Delta(U - B)$, $\Delta(B - V)$, and ΔQ values are to be applied to the observed values to obtain values appropriate for zero redshift. For example, the Coma cluster galaxies with $\langle z \rangle = 0.022$ must be made redder in $U - B$ by 0.027 mag and more positive algebraically in Q by 0.077 mag to correct them to zero redshift.[2]

V. COMA COMPARED WITH VIRGO

Equation (1), applied to the 25 Coma cluster galaxies listed in table 2 after the $U - B$ values were corrected to zero redshift, gives $\langle V_{26}\,(\text{obs}) - V_{26}\,(\text{cal})\rangle = 3.66$ mag. The dispersion of the distribution is $\sigma = 1.01$ mag, giving the probable error of the mean as $0.67\ \sigma/(n - 1)^{1/2} = \pm 0.14$ mag. Hence, between Virgo and Coma, the zero-point difference in equation (1) is 3.66 ± 0.14 mag.

The importance of this number is that it is within the range expected for the *difference in distance modulus obtained from the ratio of the redshifts*. To show this, recall that both Virgo and Coma obey the linear redshift law (i.e., $V_{26} \propto 5 \log z$) to within the dispersion in absolute magnitude of first-ranked cluster members (Sandage 1968, fig. 1). Hence, the ratio of the redshifts should be approximately the ratio of the distances.

The redshift of the Virgo cluster is uncertain. HMS gives $\langle cz \rangle = 1136$ km s^{-1}. Van den Bergh (1960) favors 1175 km s^{-1}, while de Vaucouleurs (1961*b*) divides the cluster into E (950 km s^{-1}), and S (1450 km s^{-1}) components. These are all satisfied for E and S0 galaxies by adopting $\langle cz \rangle = 1136 \pm 200$ km s^{-1}.

The mean redshift for Coma listed in HMS is 6657 km s^{-1} based on 23 values. More extensive data by Mayall (cf. Lovasich *et al.* 1961) do not appreciably change this value for the present purposes.

In the presence of an expansion without shear, the ratio of the redshifts requires

$$\Delta(m - M) \equiv 5 \log z_c/z_v = 3.84(+0.42, -0.36)\,, \quad (3)$$

TABLE 3

CORRECTIONS TO REDUCE OBSERVED COLORS TO ZERO REDSHIFT

z	$\Delta(U-B)$	$\Delta(B-V)$*	ΔQ
0.00....	0.000	0.000	0.000
0.01....	+0.009	−0.030	+0.030
0.02....	+0.023	−0.060	+0.066
0.03....	+0.037	−0.095	+0.101

* Taken from table 3 of Whitford (1971).

[2] The K-corrections of table 3 are strictly valid only for the $I(\lambda)$ distributions of giant E galaxies, because the monotonic change of $I(\lambda)$ with absolute magnitude shows that the correction itself will vary with V_{26} within a given cluster. The effect is small, being only a fraction of 0.03 mag in $U - B$ for Coma, for example, and is neglected here.

which agrees with the color-method value of 3.66 ± 0.14 to within the errors. Because it is known from other considerations that no large-scale shear component exists at the Virgo cluster (Sandage, Tammann, and Hardy 1972), and therefore that the ratio of the redshifts is the ratio of the distances, this agreement leads to the main conclusion of this paper. Elliptical galaxies in the Coma and Virgo clusters obey the same intrinsic color-magnitude effect, in the mean, to within the narrow limits of the error.

The result is illustrated in figure 2, where the standard magnitude, V_{26}, of Virgo cluster members have been made fainter by 3.66 mag, and are plotted with the Coma cluster data from table 2 after correcting $U - B$ to zero redshifts, denoted by $(U - B)_0$. The points from the two clusters intermingle. The least-squares solution from the combined data gives

$$V_{26} = -11.7(U - B)_0 + 16.35 , \tag{4}$$

with no exclusions (44 points). The correlation coefficient is $r = 0.89$.

The same analysis was made for the $V_{26} = f(Q)$ relation with the result shown in figure 3, again using $\Delta V_{26} = 3.66$ mag between the clusters. The relation is less well defined than figure 2, and it is steeper, showing that the color effect is diluted in $B - V$ (see also § VII). Least-squares solution of the combined data gives

$$V_{26} = -17.38\, Q_0 + 7.50 , \tag{5}$$

with no exclusion, where Q_0 denotes correction to zero redshift, using table 3. The correlation coefficient is $r = 0.81$. Excluding the two largest residuals, which for Coma are 38 and 59, gives

$$V_{26} = -18.9\, Q_0 + 6.98 , \tag{6}$$

with $r = 0.86$.

VI. IS A SECOND PARAMETER NEEDED? THE LOCAL GROUP

Before firm conclusions on the generality of the effect can be drawn, it will be necessary to make similar comparisons in other clusters. If all clusters can be fitted to a common relation by using appropriate ΔV_{26} shifts, the case for generality would be strengthened.

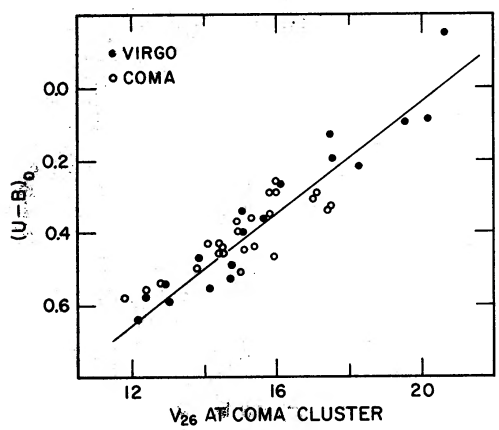

FIG. 2

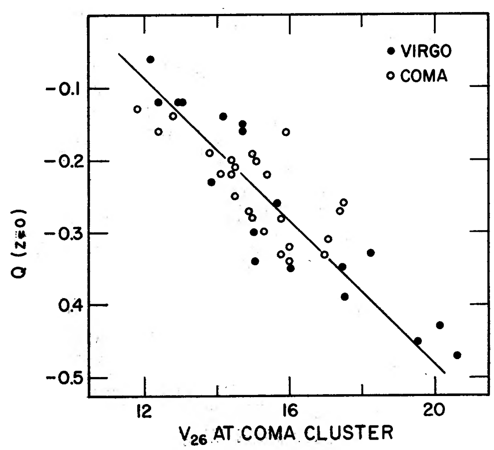

FIG. 3

FIG. 2.—Correlation of isophotal magnitude V_{26} with measured $U - B$, corrected to zero redshift. Virgo cluster galaxies have been made fainter by 3.66 mag from values listed in table 2. Two galaxies with the largest residuals have been omitted (Coma 59, M100, No. 4). They are also the galaxies with the most uncertain observational data.

FIG. 3.—Same as fig. 2 but with Q, reduced to zero redshift, as ordinate.

TABLE 4

PHOTOMETRY OF FOUR MEMBERS OF THE LOCAL GROUP

Name	A (sec)	V	$B-V$	$U-B$	Centered	V_{26}
M32....	12.19	10.50	1.01	0.45	On nucleus	
	12.19	10.53	1.04	0.42	On nucleus	
	12.19	14.14	0.95	0.23	25″ south	9.2(H)
N147...	30.60	14.68	0.91	0.32	36″ east	9.7(H)
N185...	12.19	14.84	0.87	0.34	On nucleus	9.4(H)
N205...	18.80	14.53	0.84	0.25	73″ north	
	30.60	14.22	0.81	0.22	146″ north	
	30.60	14.66	0.81	0.25	220″ north	8.2(H)

Lasker's (1970) results for the HMS groups (Humason *et al.* 1956, table 11) suggest this possibility, and many nearby clusters exist from which a further study of the problem can eventually be made. But it is interesting now to compare the galaxies in the Local Group with figures 2 and 3. Tifft (1961), de Vaucouleurs (1961*a*), Hodge (1963), and others have measured various bright members of the group with results summarized by Hodge (1963). More recently, an important measurement of the Fornax dwarf elliptical has been made by de Vaucouleurs and Ables (1968). A few measurements of M32, NGC 147, NGC 185, and NGC 205 were also made in the present study and are listed in table 4.

All these data show that the effect is undoubtedly present in the Local Group. The central region of M31 is as red in $U - B$ as the limit of figure 2. De Vaucouleurs's (1958*b*) measurement for the spheroidal component gave $U - B \simeq 0.6$, and measurements within the central 120″ reported elsewhere (Sandage, Becklin, and Neugebauer 1969) are consistent with this value. From table 4, the faint galaxy NGC 205 is much bluer, with $U - B \simeq 0.25$. For the still fainter Fornax system, de Vaucouleurs and Ables obtained $U - B = 0.08$. Hence, the effect exists.

More uncertain, however, is the absolute calibration. Plotting the equivalent of figures 2 and 3 for Local Group members, by replacing V_{26} with M_v, permits the modulus of Coma to be found by using the Local Group calibrations of $(m - M)_{\text{M31}} = 24.7$ and $(m - M)_{\text{Fornax}} = 22.0$. Shifts of figures 2 and 3 relative to the Local Group data gives a Coma cluster modulus of $m - M \simeq 33$. This cannot be correct, as it requires a Hubble constant of $H \simeq 170$ km s^{-1} Mpc^{-1} which is out of the question. Hence, although the effect exists in the Local Group, either (1) the number of galaxies (M32, N205, 185, 147, Fornax, M31 center) and their data are too fragmentary to define the relation as well as it is defined in figures 2 and 3, or (2) the Local Group members show a different zero point.

If the latter is true, a second parameter would be necessary, and the effect would not be "universal," thereby weakening the usefulness of figures 2 and 3 for determining relative distances. Observations on other groups and clusters such as those in Leo, Fornax, and the HMS aggregates are now under way to study this crucial question.

VII. DISCUSSION AND SUMMARY

The explanation of the phenomenon is likely to involve a combination of differing chemical composition and/or systematic variation of the luminosity function with galaxian mass. That the effect has such a small dispersion, characterized by $\sigma \lesssim 1$ mag at constant $U - B$ (fig. 2), is taken to indicate the existence of a heretofore unexpected regularity, either in (1) the galaxy formation process or in (2) the chemical history of galaxies considered as closed systems during the life process of their member stars of all ages. Perhaps the most unexpected conclusion to be drawn from the tightness of the correlation is that initial conditions and/or events in E and S0 galaxies appear to follow the same pattern—a pattern that varies systematically with absolute luminosity (mass).

To further study the effect observationally, it will be useful to isolate the spectral regions in which the differences are maximum. From the following data, it seems likely that most of the gross spectral differences are confined to wavelengths shortward of $\lambda \simeq 4200$ Å. (1) $B - V$ only weakly shows the progression, and then only for the faintest galaxies; there is a plateau of $\Delta V \simeq 3$ mag, starting at the bright end, over which $B - V$ does not vary (Baum 1959). Figure 2 shows no plateau in $U - B$, suggesting that the effect is more pronounced in this color. (2) The same conclusion follows by noting that equation (2) has a steeper slope than equation (1), meaning that adding $B - V$ to the relation via Q dilutes the effect. (3) The sigma of figure 3 is $\sigma(\Delta V_{26}) = 1.05$ mag compared with $\sigma(\Delta V_{26}) = 0.72$ mag from figure 2, again showing the diluting effect of adding $B - V$. (4) Whitford's comparison of M32 with NGC 4374 (Code 1959, fig. 4), and later work on more galaxies (Oke and Sandage 1968) compared with M32, require the same conclusion.

Spectrum-scans of cluster and group galaxies with a spectral resolution of $\Delta\lambda \approx 100$ Å over the range 3200 Å $< \lambda <$ 8000 Å are expected to provide data with which to optimize the spectral region of the effect.

If we keep in abeyance the problems of an explanation of the effect, and the uncertain question of its generality (§ VI), several conclusions follow from the present study.

1. The effect in $U - B$ varies continuously with absolute magnitude. Although we have fitted figure 2 linearly, it may be that a better fit would be slightly parabolic in the sense of a smaller change of $U - B$ at bright M_V. Nevertheless, the effect is pronounced, and an improvement in estimating relative distances to E and S0 galaxies in the field may be obtained if the anomalous results in the Local Group can be explained.

2. The effect of redshift on $U - B$ and Q is not negligible, even for small redshifts. K-corrections must be applied to observed values before comparisons of the color-magnitude effect can be made.

3. The magnitude shift required to merge the data on the Virgo and Coma clusters is $\Delta V = 3.66 \pm 0.14$, which agrees with the ratio of the redshifts that gives $\Delta V = 3.84 \pm 0.4$. The hypothesis of Abell and Eastmond (1968) that a hump in the luminosity function is a distance indicator requires that $\Delta V = 4.7 \pm 0.2$ between Coma and Virgo, which is inconsistent with the present result at the 2.5 σ level.

4. A change in the rate of chemical evolution, or a progressive change of stellar content (luminosity function), with total mass can be suggested as causes. Higher-spectral-resolution scans of giant and dwarf ellipticals, made in an optimized spectral region, should provide constraints on particular models.

5. Questions concerning the universality of the color-magnitude effect are raised by data for galaxies in the Local Group. The question of the need for a second parameter is not yet answered.

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