handed light produces an upward-to-the-left obliquity irrespective of the orientation of the circular polariser. Brindley[3] has suggested that the effect of circularly polarised light could be explained if any of the optical media of the eye such as the cornea were birefringent with axes vertical and horizontal.

I have repeated Shurcliff's observations using quarter wave plate compensators as a source of circularly polarised light, but have been unable to confirm his findings either in my own eyes or in those of any subject whom I have so far examined. I have, however, found that a quarter wave plate for yellow light ($\lambda = 575$ nm, retardation checked by the method of de Sénarmont and with a Babinet compensator) consistently produces in persons, including myself, who are able to see Haidinger's brushes clearly, a reversal of the figure so that its long axis lies at right angles to its previous direction. This reversal is most evident when the transmission plane of the polaroid is vertical or horizontal, and the $\frac{1}{4}\lambda$ plate is interposed between the polaroid and either eye with its slow direction in the upward-and-outward diagonal. When the $\frac{1}{4}\lambda$ plate is inserted accurately in the upward-and-inward diagonal the figure disappears. A $\frac{1}{2}\lambda$ plate, on the other hand, produces reversal in the upward-and-inward diagonal and disappearance in the upward-and-outward diagonal.

These findings are explained if the collagen in the corneal stroma is predominantly orientated in the upward-and-outward diagonal—a view which agrees with earlier work[2,6] on birefringence in the visual pathway. Collagen is positively birefringent with its optical axis lengthwise, so that its slow direction is along the length of the fibre. It is the only substance in the optical path that is sufficiently birefringent to influence the orientation of the figure significantly. Reversal will occur when the combined retardation of collagen and wave plate is near to half the wavelength of blue light, while disappearance will result from the circular or near circular polarisation occurring when the combined retardation is approximately a quarter or three quarters the wavelength of blue light.

To estimate the actual retardation produced by the corneal collagen in the upward-and-outward diagonal in my own eyes, I observed the effects of introducing into the visual path one or more compensators made from thin commercial polythene with a retardation of $^1/_{12}\lambda$. With the slow direction of the compensator in the upward-and-inward diagonal, that is, in the subtraction position with respect to the corneal collagen, the definition of the figure was enhanced by a retardation of $^1/_{12}\lambda$ and returned to normal with a retardation of $\frac{1}{6}\lambda$. These findings are compatible with a retardation due to the collagen of approximately $^1/_{12}\lambda$ (48 nm). A $^1/_{12}\lambda$ compensator in the upward-and-outward diagonal should, then, give the same combined retardation ($\frac{1}{6}\lambda$) as a $\frac{1}{4}\lambda$ compensator in the upward-and-inward diagonal, and so cause the figure to disappear.

This was found to be the case. It is now possible to explain more fully the results obtained with $\frac{1}{4}\lambda$ and $\frac{1}{2}\lambda$ plates. A $\frac{1}{4}\lambda$ plate in the addition position produces a combined retardation of $\frac{1}{3}\lambda$ which is approximately $^2/_5 \times$ the wavelength of blue light giving reversal of the figure, and in the subtraction position a combined retardation of $\frac{1}{6}\lambda$, that is, $^1/_5 \times$ the wavelength of blue light causing disappearance. A $\frac{1}{2}\lambda$ plate produces in the subtraction position a combined retardation ($^5/_{12}\lambda$) equal to $\frac{1}{2} \times$ the wavelength of blue light giving reversal, and in the addition position a combined retardation ($^7/_{12}\lambda$) equal to $\frac{3}{4} \times$ the wavelength of blue light causing disappearance.

A class experiment was conducted to determine the prevalence of a preferential orientation of the corneal collagen. One hundred students were asked to visualise Haidinger's brushes using polaroid and to report the effect on their orientation of a $\frac{1}{4}\lambda$ plate made from three layers of polythene. Eighty-three students were able to see the brushes, and of these 83% (69 students) obtained reversal with each eye when the slow direction of the $\frac{1}{4}\lambda$ plate was in the upward-and-outward diagonal and disappearance with the plate in the opposite diagonal. Because the subjects were not used to making such observations, these results may be regarded as confirmation of a predominant upward-and-outward direction for the collagen bundles in the cornea. Recent authors[7-9] have stated that the corneal collagen is randomly arranged, although Kokott's[10] reconstruction of the superficial layer of the stroma shows a mainly oblique direction with an apparent preponderance in the upward-and-outward diagonal. It may be significant that the predominant orientation shown by the present study is in the line of pull of the tendons of the superior and inferior oblique muscles of the eye.

C. C. D. Shute

Physiological Laboratory,
University of Cambridge, Cambridge, UK

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The apparent heaviness of colours

Early this century, E. Bullough[1] showed that some combinations of colours, one above the other, are chosen as more 'natural' than other combinations, which tend to look top heavy. Various methods of measuring the apparent weight of colours were subsequently devised: Bullough's preference method, tests in which the weight of coloured blocks was judged either visually or directly by hand[2,3,4], and the 'weighing' of half-inch circles of coloured paper at either end of a simulated balance arm with an adjustable fulcrum[5]. There was general agreement that red and blue were the heaviest colours, yellow the lightest. But no statistical evaluation was used in the earlier work; and as the colours were surface-illuminated, the effect of colour was easily confounded with that of brightness. In fact, most investigators considered that brightness was probably a crucial factor. In the present study, an adaptation of Monroe's procedures, the effects of colour and brightness were investigated separately using larger transilluminated stimuli, with brightness carefully controlled. Our results show that the effect is independent of brightness. Coloured circles, equal in subjective brightness, differ considerably in apparent weight, while achromatic stimuli which differ in brightness are not consistently different in weight.

The display as seen by the subjects is shown in Fig. 1. Two circular holes, 10 cm in diameter with 30 cm between centres, were cut in a matt black screen. The holes were covered by ground glass, on to which the stimuli were back-projected by two slide projectors. Between the circles was a horizontal slit along which the subject could move a small luminous pointer to the 'balance point', by turning a knob below the board. The display was positioned vertically in front of the subject in a dark cubicle, so that his eyes were about level with the stimuli and the control knob was within easy reach. Movements of the pointer were recorded on an oscilloscope screen, unseen by the subject.

We tested the effects of colour in the absence of brightness differences, and the effects of brightness in the absence of colour differences. In order to simplify the procedure, each of the test stimuli was individually 'weighed' against a white stimulus of constant brightness. For the colour experiment five colours were used: Red, Orange, Yellow, Green, and Blue (Kodak

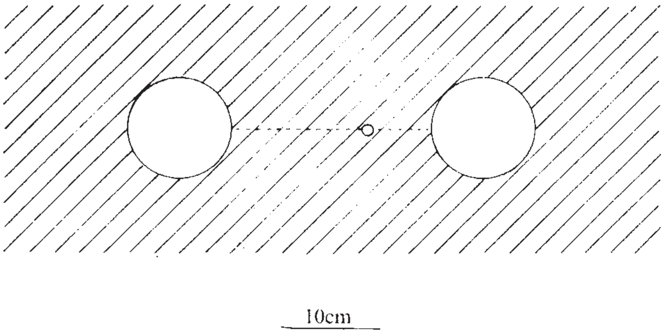

Fig. 1 The display as seen by the subjects.

Wratten filters, Nos 25, 22, 12, 58 and 38A, respectively), all adjusted to be equal in subjective brightness to the standard. For the brightness experiment white stimuli of four different brightness levels were used, covering a 25-fold range in physical intensity.

Each colour was presented eight times and each brightness level four times in the course of a testing session on one subject, giving 56 'weighings'. The brightness stimuli were mixed in amongst the colour stimuli and the whole order was randomised, with the constraint that each stimulus should appear equally often on the left and right of the display. The order was changed for different subjects to eliminate possible order effects. Medians of the judgements made to each stimulus type were used in the comparison.

Ten men and ten women took part in the experiment. All were Cambridge undergraduates, none of whom had any previous knowledge of the phenomenon being studied. Each subject was given the following printed instructions at the start of the session.

> "**The apparent weight of colours.** Pictures are often said to have a centre of gravity, perhaps determined by the way the different colours are arranged. Early this century, those investigating the psychology of aesthetics had the idea that colours have weight. This is an experiment to test that idea.
>
> Imagine the slit joining the two circles to be a rigid bar connecting two heavy illuminated spheres, and supported by the luminous pointer as a fulcrum. By turning the knob, move the pointer along the slit to a position about which the two spheres appear to be exactly balanced in weight. There are no right or wrong answers, so please do not feel that you need to take a long time to make these judgements."

No practice examples were given, though the subjects were encouraged to spend more time over the first few judgements so that they should get the idea. When the subject indicated, for each stimulus pair, that he was satisfied with the position of the pointer, this was recorded, and the next pair presented.

With the coloured stimuli most subjects had little difficulty in making these unusual judgements, although a few said that they did not accept the metaphor of 'weight', and were simply placing the pointer where it looked best. With the stimuli of different brightness the subjects appeared more unsure of what to do, and their judgements were rather less reliable.

To evaluate the results, the position of the pointer was expressed in terms of the displacement from the mid-point towards the test stimulus, positive displacements thus indicating increasing 'heaviness' relative to the standard. The medians of the 20 subjects' median judgements for each test stimulus are given in Table 1.

Table 1 Median displacement of pointer from mid-point towards the test stimulus

Colour	Yellow	Green	Blue	Orange	Red
	0.9	1.9	1.9	2.1	3.8 cm
Brightness*	−0.8	−0.4	+0.3	+0.7	
	0.2	0.4	0.2	0.3 cm	

*Brightness given in log-foot-lamberts relative to standard

All the colours were regarded as heavier than the standard, with red the heaviest, yellow the lightest and the other three clustered in between. A Friedman two-way analysis of variance by ranks indicates that the effect of colour was highly significant ($P < 0.001$). On a Wilcoxon matched pairs test, yellow comes out as significantly lighter than all the other colours ($P < 0.05$ or better), and red as significantly heavier than green, orange and yellow.

Table 2 Average ranks attributed to each colour

	Red	Blue	Green	Orange	Yellow
Men	0.70	1.65	2.25	2.10	3.30
Women	1.05	1.75	1.65	2.50	3.05
Total	0.87	1.70	1.95	2.30	3.17

0, heaviest; 4, lightest.

The average ranks (from 0 as the heaviest to 4 as the lightest) attributed to each colour are shown in Table 2. Though the rank ordering of the different colours was generally consistent across subjects, there was considerable variation in the absolute distance to which the pointer was displaced, some subjects tending to stick close to the mid-point, while others used nearly the full length of the slit (the inter-quartile range for red extended from 1.7 – 5.7 cm). Men and women gave essentially similar results.

The results for brightness showed no significant effects of any kind.

No plausible explanation has yet been offered for why people should see any equivalence between colour and weight, nor can we offer one. Bullough suggested an explanation in terms of landscape associations and aerial perspective; but he himself considered this aurgument *ad hoc* and unconvincing. Indirect associations, of the kind 'red = important = heavy', seem more likely. Red is commonly regarded as a particularly striking colour; moreover, in tests of colour preferences, red and blue are generally considered the most pleasant colours, yellow the least pleasant. A correlation between saliency or colour preference and apparent weight, however, if it exists, has little explanatory power. The reasons for colour preferences are themselves unclear. Whatever the explanation, the consistency with which people make such peculiar 'synaesthetic' judgements about the affective value of colours is remarkable.

ELIZABETH PINKERTON*
N. K. HUMPHREY

Psychological Laboratory,
University of Cambridge,
Cambridge, UK

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*Present address: The Applied Psychology Unit, Admiralty Research Laboratory, Teddington, Middlesex.

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Male sterility induced in barley by photoperiod

THE continuous exposure of barley plants to short photoperiods leads to marked increases in the numbers of primordia and grains per ear[1–4]. But little is known of the effects of brief exposures to short days and here we describe the distinctive effects of such