THE MODERN THEORY OF COLOR.

A LECTURE BY PRESIDENT HENRY MORTON, OF THE STEVENS INSTITUTE OF TECHNOLOGY.

In a lecture, recently delivered at the Stevens Institute of Technology, President Morton explained our perception of color in accordance with the generally received modern theories on the subject, which he illustrated by means of many ingenious and striking experiments. The following is the substance of the lecture:

Color, physically considered, is synonymous with wave-length, light being composed of minute undulations or waves, varying in length from the $\frac{1}{35000}$ to the $\frac{1}{60000}$ of an inch, the former being the length of the red, and the latter of the violet wave. These waves strike the eye with a velocity of 185,000 miles per second. Nearly 200,000 miles of them, therefore, enter the eye in every second; and every inch of these miles contains between 35,000 and 60,000 little waves. The whole number in a single ray is so enormous that it conveys no impression to our minds. Counting five every second, day and night, it would take about three millions of years to count what the eye receives in a single second. Yet, the eye, when perceiving colored objects, not only takes cognizance, in some mysterious way, of these rapid motions, but even distinguishes their rates of velocity. Between the rates of motion of the colors at the extremities of the spectrum, there might be an infinite number of intermediate rates, and hence of intermediate colors and shades. Evidently, however, the eye is incapable of discriminating more than a very limited number. And this brings us to the consideration of the eye itself, and the means by which we perceive color.

Fig. 1.

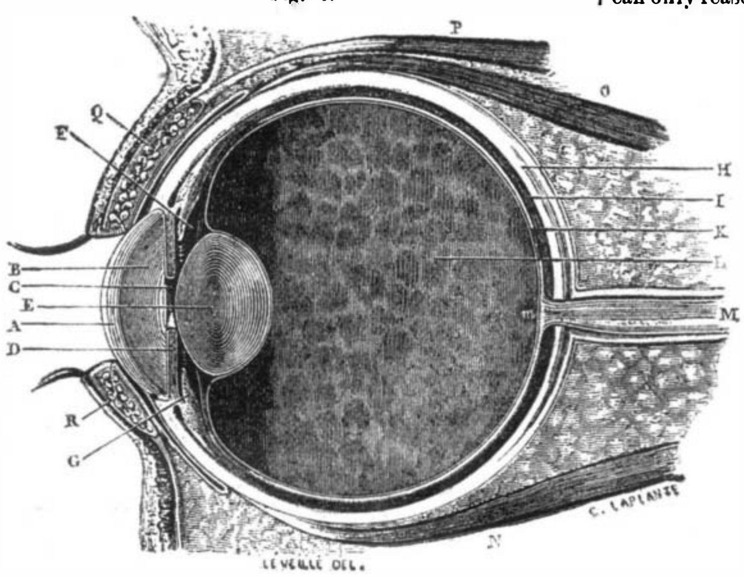


Fig. 1 exhibits the general structure of the eye. It is like a photographic camera, or dark chamber, with its lens in front and a sensitive plate behind; only, instead of being coated with collodion, the sensitive part is a hollow sphere, covered with a delicate network of nerve structure, called the retina, which it is well worth our while to examine a little more in detail.

Fig. 2.

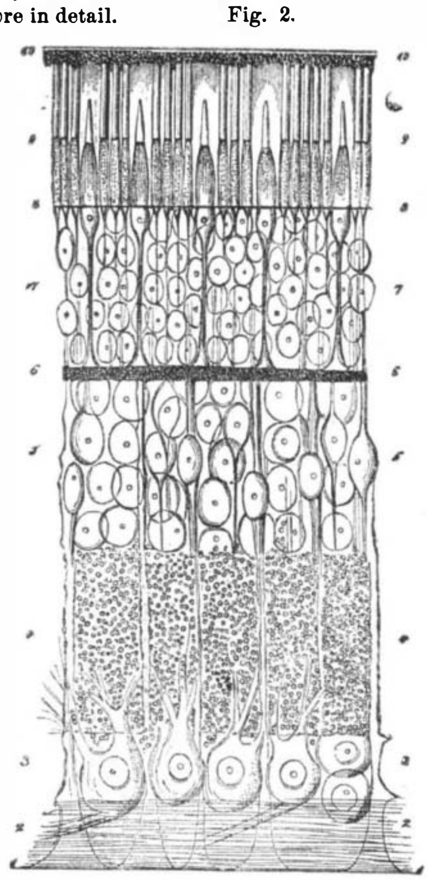
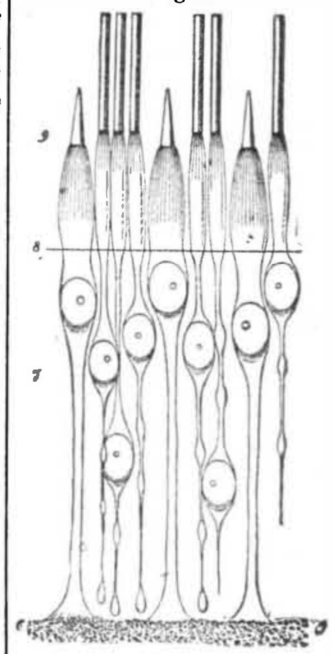


Fig. 2 shows the layers of the human retina magnified 400 times. There are no less than ten of them, all of which, with the exception of the two terminal ones, are made up of nerve tissue and connective substance. As the figure stands, the light enters from the bottom. The vibrations communicated to the nerve substance finally reach the ninth layer, where experiments, which it would take too long to describe here, have led investigators to believe that the sensation of sight is located. This layer, called the "rods and cones," from the shapes assumed by the optic nerve substance there, is supposed to be tuned to the reception of color vibrations, just as the rods of the auditory nerve are tuned to sound vibrations. Fig. 3 gives a still more enlarged view of the rods and cones, showing their peculiar structure much more plainly. Each of them is in communication with a so-called granule, forming an enlargement which contains a nucleus. In life the granules are entirely transparent. Professor Max Schultze says: "The rods and cones must be considered the nervous terminal organs of the optic nerve; in them must take place the translation of the action of light into nervous action, which process ultimately lies at the foundation of the act of vision."

Fig. 3.



On still further magnifying these curious organs, it will be seen, from Fig. 4, that even they, minute as they are, are divided into still more minute parts. What the functions of these ultimate parts are, we cannot tell; although we have reached the extreme end of the optic nerve, and have seen its wonderful complexity, we can only reason that the conversion of light into sight must take place here; but we do not seem to have approached a knowledge of *how* it is accomplished by a single step. The whole subject lies far out in the *terra incognita* of Science, and it is only intended here to state the problem as it stands at present, and to show through how tangled a jungle the path of knowledge lies in this direction.

Passing now from the anatomical considerations of the subject, we will examine the theoretical view proposed by Thomas Young, and more fully developed by Helmholtz. According to this theory, the eye perceives originally but three colors or wave lengths, and all the other colors and shades known to us arise from the compounding of the primary ones in the eye. Accordingly, we assume that the eye has three sets of nerves—one affected by red, another by green, and a third by violet. In other words, the nerve for red is tuned to vibrate to red waves of light, just as a tuning fork is set in vibration by communicating with a body sounding its note; and so with the other nerves. Each of these nerves, however, is capable of being affected, though in a much inferior degree, by colors be-

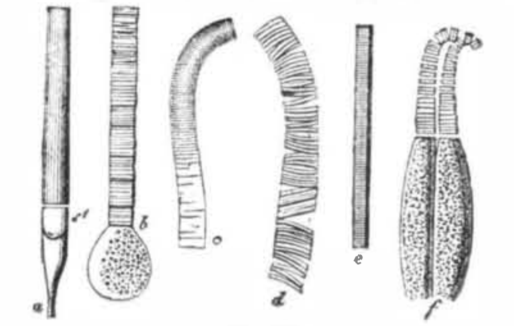


Fig. 4.*

longing to the others. Thus the red nerves would be somewhat sensitive to green waves, but would perceive them as a faint red. If, for example, we look at blue light, whose rate of vibration is intermediate between green and violet, it will affect the green and the violet nerves, producing a mixed impression, which we call blue.

Let us try and prove this. If blue is to the eye simply the result of a combined impression of green and violet, then, by exciting both the green and violet nerves by means of the corresponding colors, we ought to get a perfect impression of blue; but if the eye recognizes blue as a distinct thing, then a mixture of green and violet light will give the impression of something not identical with blue.

The lecturer then threw two disks of light on the screen, one violet and the other green; where they overlapped the result was a beautiful blue, as represented in Fig. 5.

Fig. 5.

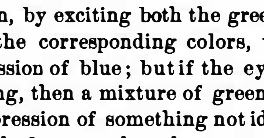
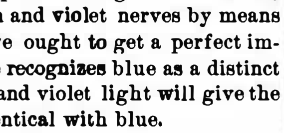


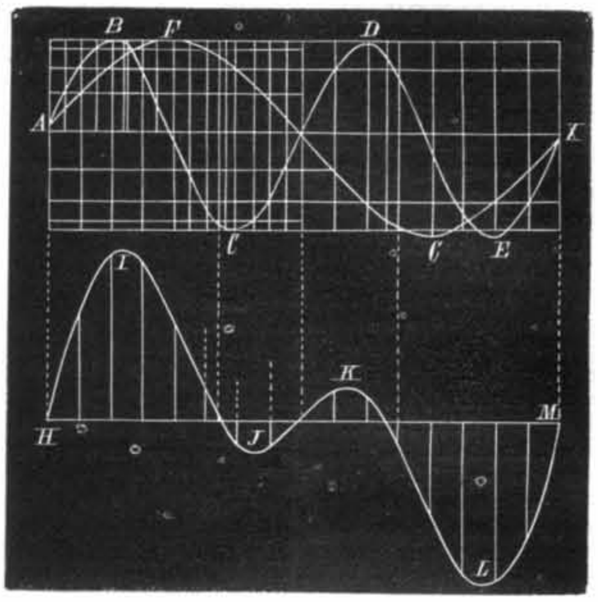
Fig. 6.



Similarly red and green disks of light, thrown on the screen, produce the compound impression we call yellow (Fig. 6).

It may be asked, however: Is not blue, being an intermediate wave length between green and violet, in fact their true average and equivalent? To show that this is not the proper manner of considering the question, it is only necessary to look at the manner in which waves combine. In the engraving, Fig. 7, we have two waves, one twice as long as the other, and below them is their resultant, obtained as follows: Both waves, starting at A, pass up in the same direction; their combined effect is therefore equal to their sum

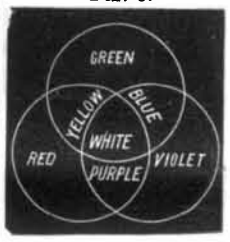
Fig. 7.



which is represented at the point, I, below; again, at the point, C, the effect of the motion of one curve below the axis, A X, is diminished by the motion of the other above the axis; the resultant point being their difference in hight, and on the same side of the axis as the greater. This point is represented at J. By combining, in like manner, all the corresponding points of the two curves, the resultant curve, given below, will be produced, and this curve certainly does not look like the average wave of the two, being, in fact, a very different kind of motion from either of its constituents.

But, to follow out the consequences of Young's theory, although white light, as we know from the prism, is composed of all colors, the eye directly perceives but three of them. Therefore if we take these three colors and present them at once to the eye, the effect ought to be white.

Fig. 8.



The lecturer then threw on the screen disks of green, red, and violet, by means of three lanterns. Where all three overlapped, the result was white; where red and green combined, the result was yellow; and where green and violet combined, the result was blue; thus satisfying the requirements of Young's theory (Fig. 8).

The lecturer then proceeded to prove these important results by other means. When an image is presented quickly to the eye and then withdrawn, the eye retains the impression for a short time after the actual image has ceased to exist on the retina. This is the phenomenon known among physicists by the name of persistence of vision. To illustrate this property, which was soon to be employed in elucidating the theory of colors, a series of dots, moving forward and back like shuttles, was thrown on the screen. As the velocity of their motion was increased, the impression made by each of them, at every part of its course, remained on the retina long enough to allow it to come around again and refresh the memory, thus seeming to describe continuous wreaths of light. A very beautiful effect was produced on the same principle by having a large revolving disk, with globes in different positions with regard to hoops painted upon it, illuminated with flashes of intermittent light produced by revolving before the source of light a disk of pasteboard with a number of slits cut radially on it. The large disk seemed to stand still and the balls to roll through the hoops with great rapidity.

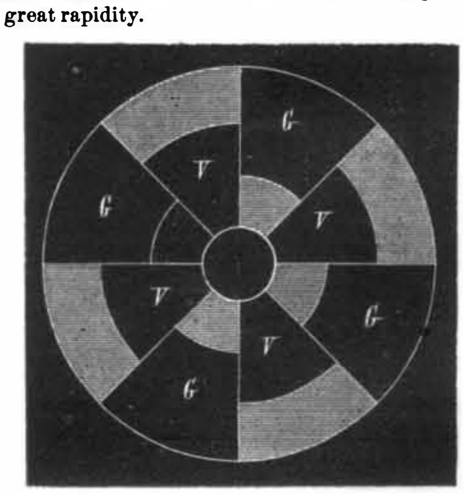


Fig. 9.

The principle of the persistence of vision may be applied to obtaining the blending of colors upon the retina, by presenting them in quick succession to the eye. Professor Rood's chromatrope is an instrument for effecting this. It consists of a disk of glass, clear at the center, opaque in the shaded parts, and colored green and violet, as indicated by the letters in Fig. 9. On revolving this disk rapidly, there was an outer zone of green and an inner zone of violet; but between them, where, by its revolution, green and violet are presented successively, the impression of green remained long enough for that of violet to combine with it in the eye and

* We are indebted to Messrs. Wm. Wood & Co. for the electrotypes of cuts Figs. 2, 3, and 4, from Stricker's great work on "Histology."

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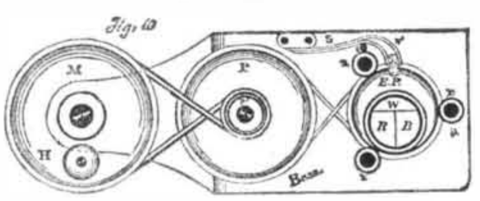
to produce a zone of blue. Disks with other combinations of colors were also shown.

The most striking effect of the lecture, however, was produced by means of a very ingenious invention of Professor Morton. He calls it the "chameleon top," and its construction is well worth studying. An opaque disk, with W (Fig. 10) for a center, is made to revolve before a lantern by means of the large pulleys, M and P. It has no axle, but is in friction gearing with the little pulleys, x x x. In this opaque disk, there is a transparent one, W R B, composed of seg-

Fig. 10.



ments of white, red, and blue glass, as shown in the engraving. The transparent disk, moreover, is set in the other one loosely, so that its motion may be suddenly checked by means of an elastic pad, E P, while the large disk is in full revolution. By this means the center is shifted from one color to another. Now let us see the result of that. When the instrument is at rest, nothing appears upon the screen, except a very unpromising disk divided into three portions. But the moment it begins to revolve, the colors blend in various ways, forming rings of ever changing hues, which succeed each other like those of the most gorgeous pinwheels of pyrotechnics. Suppose the disk revolves with its center in the white, then the blending of colors in each zone can be studied from the circles of Fig. 11; Fig. 12 represents the

Fig. 11.

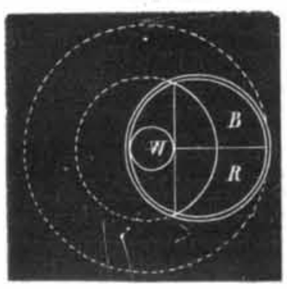
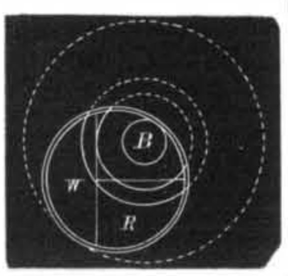
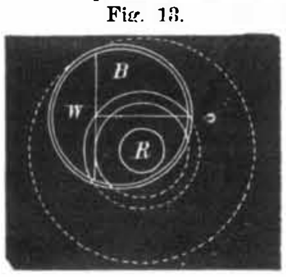


Fig. 12.



effect when the center is changed to blue, and Fig. 13, when it is shifted into the red. The dotted portions of the zones are those seen by persistence of vision. Now, by means of rapidly pressing the elastic pad against the projecting rim of the transparent disk, there is a constant shifting of centers, and the result is an infinite variety of splendid effects.

Fig. 13.



There is still another way of proving the theory of color. By throwing on the screen the intense light obtained by burning mercury, and by burning steel in the electric arch, the eye does not distinguish them; but by passing these lights through a prism, they are proved to contain very different elements. In fact, it would be all the same to the eye, if only the three primary colors existed and no others, for the result would be the same; when combined they would form white light.

Now, how do we know that the primary colors are red, green and violet, and not red, yellow, and blue, as we were taught years ago, and as Sir David Brewster maintained? An experiment will answer this question. If red, yellow, and blue are the primary colors, then green must be a mixture of yellow and blue. According to Young's theory, however, yellow and blue are equivalent to white; because by them we excite all the nerves, yellow being equal to red and green, and blue being equal to green and violet. If Brewster is right, blue and yellow light will make green; if Young is right, they will make white. The lecturer then threw the two colors from two lanterns on the screen by means of colored glasses. The result was white. The same result was obtained with the chromatrope.

How does it come, then, that blue and yellow paints mixed produce green, as every child knows?

The color of paints is due to the light passing through them to the paper and reflected from the paper under them. Now, white light passing through blue paint is robbed of every color except blue, green and violet; passing through yellow paint, it is robbed of all but yellow, red, orange, and green. Green, therefore, is evidently the only color that both are agreed in transmitting through them. The same effect is produced by taking the very glasses, blue and yellow, whose combination just produced white, and allowing the same white light to pass through both, instead of having separate sources of light. The result is green, because the combined glasses cut off every other color.

There is another property of the eye with regard to the perception of color, which must not be overlooked. Like all other organs of the body, the eye is easily fatigued. If we look at red light for a long time, the nerves vibrating with it become so tired that they cease to act; if now the red is suddenly withdrawn and white substituted, the other two sets of nerves, namely, the green and violet, either act alone or are but faintly seconded by the red; and the consequence is we do not see white at all, but a shade of green. This was strikingly shown by an experiment. Two lanterns, side by side, threw on the screen, one pure white light, and the other red. After the audience had looked at it awhile, Professor Morton placed himself in such a position as to cast two shadows on the screen; one of them was red, of course, but where only white light fell the shadow was blue green. On substituting green light for the red, the shadow falling on the white part of the screen looked red. This is the principle of contrast in color, which many an artist has no doubt carried out in practice without suspecting the cause. As an illustration of a well known effect of contrast, the Professor threw on the screen a piece of statuary, and then gave it a background of green foliage by means of another lantern, the effect of which was to endue the statue with a warm tint of red.

In conclusion, the lecturer remarked that he did not wish to convey a false impression when speaking of certain imperfections of the eye. "Helmholtz, one of the most eminent physicists of the day, has used an expression with reference to the subject, which, when quoted alone, without the general spirit of the context, might convey the idea that he considers the eye as a bungling piece of workmanship unworthy of any skillful optician. Any candid reader who peruses the whole article will find that this is as far from the meaning of the author as it is from the fact. Discrimination between wave lengths is not only not the true office of the eye, but would be quite inconsistent with its varied and indispensable functions as an organ of vision. It is perfectly true that the eye, as a spectroscope, is a very poor instrument; but who, when gazing at the glories of a crimson sunset, at the beauties of a variegated landscape, or the blended roses and lilies of a pretty face, would exchange his eyes for a pair of the finest spectroscopes that ever left the shop of the most skillful physicist?" C.F.K.

How American Workmen Live.

A recent annual report of the Massachusetts Bureau of Statistics contains some interesting facts touching the wages and manner of living of working people in that State. It may be assumed we think, that in no State of the American Union is the average situation of the working man any better, but, if any different, will be found rather below than above that of Massachusetts.

The statistics, upon which the facts given are based, were gathered by personal visits of the Bureau officers in all parts State, and were obtained from the workmen in all branches of skilled and unskilled labor. Complete returns were obtained from 397 families, and the condition of this number is presented in detail, as shown in the following example:

CARPENTER.

Annual earnings of father (American), $760, being an average of $243 cents per diem, paper currency.

Condition: Family numbers five, parents and three children from three to ten years of age; two go to school. Have a tenement of five rooms located in a good neighborhood with pleasant surroundings. The rooms are well furnished and the parlor carpeted. Have a sewing machine. The family dresses well.

Food: Breakfast, hot biscuit, butter, meat or eggs, cake and tea; dinner, bread, butter, meat, potatoes, vegetables, pie; supper, bread, butter, sauce, cake, and tea.

Rent	$132.00	Fish	$10.00
Fuel	37.00	Milk	17.90
Groceries	346.22	Boots and shoes	26.30
Meat	80.50	Clothing	50.00
Dry goods	19.84	Religion	10.00
Papers	8.00	Sundries	13.24
Cost of living			760

All of the statements are presented with this same detail, and give a picture of the home economies of the State that is both interesting and instructive to all wage laborers. By these statements it is shown that five families out of 397 invested in furniture and carpets; 264 families, or 66 + per cent of the whole number, expended an average of $9 yearly for books and newspapers; 34 per cent paid society dues, and the same percentage devoted money to religion. Of the 397 families, 11 + per cent have pianos or cabinet organs; 34 + per cent have sewing machines, and, in addition to this labor-saving article, many possessed wringing machines, as will be found by reference to the family statements; 52 + per cent had one or more carpeted rooms, in many instances, as stated in the individual presentations, the entire tenement of five or six apartments being carpeted; 26 + per cent paid rates for church pews.

Of the 142 families in which the father was the only worker, the average income was $723.82. Of the 255 families in which the wives or children assisted, the average income was $784.38. The average income of the families of skilled laborers (including overseers) was $823 60, while of unskilled laborers' families $687.05 formed the average income; and of the total expenditure of the 397 families, 58 per cent was required for subsistence, 14 per cent for clothing, 16 per cent for rent, 6 per cent for fuel, and the balance of 6 per cent was devoted to sundry expenses.

From the statements and tabulated returns, the Bureau has drawn the following conclusions:

As regards earnings: That in the majority of cases workingmen in the Commonwealth do not support their families by their individual earnings alone; that the amount of earnings contributed by wives, generally speaking, is so small that they would save more by staying at home than they gain by outside labor; that fathers rely, or are forced to depend, upon their children for from one fourth to one third of the entire family earnings; that children under 15 years of age supply, by their labor, from one eight to one sixth of the total family earnings.

As regards expenses: That, judging from the proportionate outlay for dress, as regards entire expenses, there is no evidence that the working men we visited, in obedience to fashion, indulge in an excessive or disproportionate expenditure; that, from our investigations, we find no evidence or indication that working men spend large sums of money extravagantly or for bad habits: that, as regards subsistence, rents, and fuel, the working men's families which we visited paid therefor larger percentages of their income than do working men's families, with like incomes, in Prussia and other European countries; and that, as regards clothing and sundry expenses, our working men's families paid therefor smaller percentages of their income than do working men's families, with like incomes, in the countries mentioned above.

As regards manner of living: That, among the families visited, those containing the greatest number of child workers occupy the most crowded rooms and the inferior class of tenements; that about three quarters of the working men's homes which we visited are in good condition as regards locality and needful sanitary provisions, but that nearly one half of the unskilled laborers live in the inferior tenements; that the working classes of Massachusetts, judging from our investigations, are well fed; that, as far as our investigations extended, our working men are, on the average, well and comfortably clothed; that their manner of dress is, at least, capable of most favorable comparison with that in foreign countries; that a large proportion of the skilled working men visited have sewing and other labor-saving machines in use in their families; and that, as evidences of material prosperity to a certain extent, significant numbers of the families, the aid of child labor being fully allowed, own pianos or cabinet organs, have carpeted rooms, and maintain pews in church.

As regards savings: That more than one half of the families visited save money; less than one tenth are in debt, and the remainder make both ends meet; that without children's assistance, other things remaining equal, the majority of these families would be in poverty or debt; that savings, by families and fathers alone, are made in every branch of occupation investigated; but that in only a few cases is there evidence of the possibility of acquiring a competence, and in those cases it would be the result of assisted or family labor; that the higher the income, generally speaking, the greater the saving. actually and proportionately; that the average saving is about three per cent of the earnings, and that, while the houses of the working men visited compare most favorably with those in foreign countries and other States of the Union, yet in certain of the United States working men have better opportunities for acquiring homes of their own.

From these conclusions, it is asserted that, while the wage system enables a minority of the working men to maintain themselves and families comfortably by their individual exertions, in a majority of cases they have to have aid from wife or children to accomplish this result.

Pneumatic Railway Signals.

At Wilmington, Del., the Philadelphia, Wilmington and Baltimore Railroad Company has recently put down, on trial, a new railway signal and gate system. Along or between the tracks, or under the road, a pipe is laid, 2 inches in diameter, in which compressed air, 85 lbs. to the inch pressure, is carried. When the train moves out of the depot, the locomotive strikes a lever; and at the first street which the track crosses, a gong or bell is set ringing, to warn persons that a train is approaching, and a gate extending across the street descends to within two feet of the ground. The gate remains closed until the train has passed. The locomotive then strikes another lever, when another bell is rung, and another gate a square ahead is closed; and the gate behind the train is caused to rise to its place, and that crossing is left free. In this manner every train that passes through a city is made automatically to fence itself in, as it were, by closing and opening gates over each street, one or two squares in advance as may be desired.

When the train starts, by its striking the lever already described, a danger signal is instantly thrown around at right angles to the track behind the train, and another a mile ahead of it. When this one is reached another lever is struck, and the last mentioned signals are thrown back to their former positions, showing the first mile to be clear; and the two other signals, one behind and one a mile ahead of the train, are exposed, and so from mile to mile along the whole road. At every point of its progress a train is thus between two signals, one to warn trains coming toward it, the other to warn trains following it.

The Way to Get Along.

Twenty clerks in a store, twenty hands in a printing office twenty apprentices in a shipyard, twenty young men in a village—all want to get along in the world, and expect to do so. One of the clerks will become a partner, and make a fortune; one of the compositors will own a newspaper, and become an influential citizen; one of the apprentices will become a master builder; one of the young villagers will get a handsome farm, and live like a patriarch—but which one is the lucky individual? Lucky? There is no luck about it. The thing is almost as certain as the rule of three. The young fellow who will distance his competitors is he who masters his business, who preserves his integrity, who lives cleanly and purely, who devotes his leisure to the acquisition of knowledge, who gains friends by deserving them, and who saves spare money. There are some ways to fortune shorter than this old, dusty highway; but the staunch men of the community, the men who achieve something really worth having, good fortune, good name, and serene old age, all go in this hard, dirty road.—*Exchange.*

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