The Fundamentals of Photography [1]

By C. E. K. Mees

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Chapter I – The Beginnings of Photography

The first person to notice that chloride of silver was darkened by light may have been J. H. Schulze, who made the discovery in 1732. It is probable, however, that this had been observed by others. In 1737 Hellot in Paris, was trying to make sympathetic inks, that is, inks that would be invisible when put on paper but which could be made visible afterwards. He found that if he wrote on paper with a solution of silver nitrate, the writing would not be visible until the paper was exposed to light, at which time it would turn dark and could be read. However, no use was made of these discoveries for the purpose of making pictures until 1802, when Wedgwood published a paper entitled "An Account of a Method of Copying Paintings on Glass and on Making Profiles by the Agency of Light upon Nitrate of Silver."

This reference to making profiles is a reference to one of the forms of portraiture which preceded photography. Before portrait photography was discovered, there were people who made what were called "silhouettes", which were profile pictures cut out of black paper and stuck on to white paper. Some of these silhouettists were very clever indeed. Others who had not great ability arranged their sitter so that they got sharp shadows thrown by a lamp onto a white screen and this gave them the profile to copy. Wedgwood thought that instead of cutting out the silhouette he might print this profile on the screen by using paper treated with silver nitrate, which would darken in the light. Wedgwood not only used his new process to record these silhouettes, but he tried to take photographs in what was then called the "camera obscura", which was the forerunner of the Kodak of to-day.

The camera obscura consisted of a box with a lens at one end and a ground glass at the other, just like a modern camera. It was used by artists to make a picture of anything they wanted to draw, as by observing the picture on the ground glass they could draw it more easily. Wedgwood tried to make pictures in his camera obscura by putting his prepared paper in the place of the ground glass. His paper however, was too insensitive to obtain any result; but Sir Humphrey Davy, who continued Wedgwood's experiments, using chloride of silver instead of nitrate, succeeded in making photographs through a microscope by using sunlight. These are apparently the first pictures made by means of a lens on a photographic material.

But all these attempts of Wedgwood and Davy failed because no method could be found for making the pictures permanent. The paper treated with silver chloride or silver nitrate was still sensitive to light after part of it had darkened, and if it were kept it soon went dark all over and the picture was lost. Davy concluded his account of the experiments by saying: "Nothing but a method of preventing the unshaded parts from being coloured by exposure to the day is wanting to render this process as useful as it is elegant."

This much needed method, however, remained wanting from 1802 until 1839, when Sir John Herschel found that "hypo", which he had himself discovered in 1819, could dissolve away the unaltered chloride of silver and enable him to "fix" the picture, as the process has been called ever since Herschel made the discovery, and from that time to this hypo has been the mainstay of the photographer, enabling him to fix his pictures after he has obtained them.

In the meantime, Niepce in France had been working on an entirely different process, depending on the fact that such substances as resin or asphalt became insoluble when exposed to light, and he had succeeded in producing results by taking advantage of this property. In France also, Daguerre was working on various methods by which he hoped to make photographs, and entered into partnership with Niepce, but in 1839 Daguerre published the method of photography which was named for him - Daguerreotype. This was the first portrait process and became very popular. It depends upon the sensitiveness of plates of metallic silver which have been fumed with iodine so that the surface is converted into a thin layer of silver iodide. The plates so treated are exposed to light, and after a very long exposure, as we should consider it now, the plate in the dark is exposed to the vapor of metallic mercury, which deposits itself upon the image and produces a positive image of mercury upon silver.

The results were very beautiful, but these early processes of photography required very great exposures so that at first the unfortunate subject had to sit for as long as ten minutes in the full sun without moving in order to impress the plate sufficiently. Although many experiments were made in an attempt to find substances more sensitive to light so that the exposure could be reduced, the only real solution was to find some method by which light had to do only a little of the work and the production of the image itself could be effected by chemical action instead of by the action of the light.

A great step in this direction was taken by Fox Talbot in 1841. He found that if he prepared a sheet of paper with silver iodide and exposed it in the camera he got only a very faint image, but if after exposure he washed over the paper with a solution containing silver nitrate and gallic acid, a solution from which metallic silver is very easily deposited, then this solution deposited the silver where the light had acted and built up the faint image into a strong picture. This building up of a faint image or, indeed, of an image which is altogether invisible, into a picture is what is now called "'development". If we expose a film in the Kodak and then, after the shutter has allowed the light to act for a fraction of a second on the film, look at the film in red light, which will not affect it, we shall not be able to see any change in the film. But if we put the film into a developing solution, the invisible image which was produced by light, and which in photographic books is called "the latent image" will be developed into a black negative representing the scene that was photographed.

Fox Talbot was not only the first to develop a faint or invisible image; he was also the first man to make a negative and use it for printing. What is meant by a negative is this: If we look at our film after we have exposed and developed it, we shall find that the sky, which was bright in the picture, is shown in our film as very black,while any shadows in the picture, which, of course, were dark, will be transparent in the film, so that the light let through the film is in the reverse order of the scene photographed, all the bright parts in the scene being dark in the film and the dark parts bright. For this reason the film is called a "negative," and when it is printed on paper the same reversal happens again and the clear parts in the negative become dark in the print while the dark parts of the negative protect the paper from the action of the light, so that the print which we may call a "positive," represents the scene as it appeared.

Fox Talbot, then, made two of the great steps in the advancement of photography when he found how to expose his paper for a time insufficient to darken it completely, and then to develop a negative which he could print on paper covered by silver chloride. Of course, the paper was not transparent as our film is, but he made it more transparent by treating it with oil or wax. In this he was followed many years afterwards in the Eastman roll holder, which was the forerunner of all the Kodaks. In this roll holder at first a paper film was used to make the negative and then the paper was made transparent for printing.

Fox Talbot's paper negatives were succeeded by the method known as the wet collodion process, which has survived to the present day. This is the process chiefly used by photo-engravers for making the negatives from which they make the engraved metal plates for printing pictures.

Collodion is made by dissolving nitrated cotton, such as is now used for the film base, in a mixture of ether and alcohol. The worker of the wet collodion process had to make his own plates at the time when he wanted to take a picture. He would clean a piece of glass and coat it with the collodion in which the chemicals were dissolved and then put the plate in a bath of nitrate of silver, which formed silver iodide in the collodion film and made it sensitive to light. Then the glass had to be exposed in the camera while wet, and immediately after exposure it was developed by pouring the developer over it. It was then fixed and dried.

In order to carry out these operations a photographer who wanted to take landscapes had to carry with him a folding tent which he could set up in the open air. The tent was dark except for a yellow or red window by which to see to make the plates and develop them.

All this difficulty in working disappeared with the coming of the gelatine emulsion process, which is the one now used. The sensitive coating on films and papers now consists of a bromide or chloride of silver held in a thin sheet of gelatine, the gelatine being dissolved in hot water, the silver salt formed in the solution, and the warm solution of gelatine containing silver then coated on the film or paper.

The gelatine solution with the silver in it is called an "emulsion" because of the way in which the silver remains suspended in the gelatine. The first gelatine emulsions were made in 1871 by Dr. Maddox. An emulsion made in much the way that we use now was first sold in 1873 by Burgess. At first the early experimenters made and sold the emulsion itself, drying it for sale so that photographers had to take this dried emulsion, melt it up in hot water, and coat it on their plates. After a time, however, people realized that this was a great deal of trouble and that there was no reason why the manufacturer of the emulsion should not coat the glass plates with it, and sell the ready prepared plates. In those days all negatives were made on glass plates. These plates were coated with the emulsion by hand and then when the emulsion was spread over them were put on to cold level slabs for the jelly to set before drying. Glass plates are cumbersome and heavy, and for this reason George Eastman continually experimented to substitute a light, flexible support for the brittle and heavy glass. As already mentioned, he first used paper as a support for the negative, waxing it to make it transparent for printing. This was followed by a paper from which the film carrying the image was stripped, the film being transferred to a glass plate coated with gelatine so that this gelatine made a support for the film.

While experimenting to find a more satisfactory material for coating the film than gelatine it was found that a solution of nitrated cotton would make a clear, transparent and flexible support, and after a period of further experimenting this material was adopted and a roll film was made, the emulsion being carried on the clear, transparent sheet of film support. The only remaining difficulty with this was its tendency to curl owing to the gelatine coating on one side, and this was overcome by coating the other side with plain gelatine, thus producing the non-curling (NC) film.

Chapter II – Light and Vision

Light is the name which we give to the external agency which enables us to see. In order to see things we must have something which enters the eye and a brain to explain it to us. That which enters the eye is what we call light.

The eye consists of two principal parts and can best be understood by analogy with the camera. In front it has a lens which forms an image on the sensitive surface, which is called the retina, the retina playing the same part in the eye that the film does in the camera. The retina, however, differs from the film in that when light falls upon the film it produces a permanent change, which can be developed into a picture, and if the light falls upon the film for too long a time the film is spoiled, while the retina merely acts as a medium to transmit to the brain the sensation of the light that falls upon it, and when the light stops, the sensation stops and the retina is ready to make a new record. The retina behaves, in fact, like a film in which the sensitive material is continually renewed.

It is probable that this sensitive material in the eye is really of a chemical nature because it is apparently produced all the. time, and when the eye is kept in the dark the sensitive material accumulates for some time so that the eye becomes more sensitive, while when a strong light falls upon the eye, the sensitive substance is destroyed more rapidly than it is produced and the eye becomes less sensitive.

In this way, the eye has a very great range of sensitiveness. In bright sunlight it is as much as a million times less sensitive than it is after it has been kept for an hour in the dark, and it changes very rapidly, only a few minutes being necessary for an eye that has been in almost complete darkness to adapt itself to the glare of out-door lighting. In order to lessen the shock of changing light intensity, the lens of the eye is provided with an iris diaphragm just like that of a camera, but with the additional advantage that it operates automatically, opening and closing according to the intensity of the light. Measurements of the movements of the iris of the eye have been made by taking motion pictures of the eye when suddenly illuminated by a bright light, and these show what a wonderful instrument the eye is in its adaptation to changing conditions in the world around it.

The retina is connected with the brain by a great many nerve fibers, each fiber coming from a different part of the retina, so that when light falls upon any part of the retina, the intensity of the light is communicated by the tiny nerve coming from that part of the retina to the brain and the brain forms an idea of the image on the retina by means of the multitude of impressions from different parts of the retina.

The image on the retina is inverted like all lens images, so that we really see things standing on their heads, but the brain interprets an inverted image on the retina as corresponding to an upright external world, and although the eye sees things upside down, the brain has no idea of it.

What we observe is the light which falls on the retina, but this light comes originally from some external source which, in the case of daylight, of course, is the sun. The light from the sun is reflected by the objects in the world around us according to their nature, and entering the eye it enables us to see the objects. When we look at a landscape we see that the sky is bright and the roads and fields are less bright, and the shadows under the trees are dark, because much of the light of the sun is reflected from the sky, less from the fields and roads and still less from the shadows under the trees. All these rays from the sun reflected from the natural objects in the landscape enter the eye and make a picture on the retina which is perceived by the brain by means of the tiny nerve fibers coming from the retina to the brain.

But the eye not only perceives differences in the brightness of the light - it also observes differences in colour - and in order to understand how this can be we must search further into the nature of light itself.

The nature of light has long been a source of speculation, and at one time it was generally held that the light which entered the eye consisted of small particles shot off from the source of light, just as at one time it was held that sound consisted of small particles shot off from the source of a sound which struck the drum of the ear. This theory of light has the advantage that it immediately explains reflection; just as an india rubber ball bounces from a smooth wall, while it will be shot in almost any direction from a heap of stones, so the small particles of light would rebound from a polished surface at a regular angle, while a rough surface would merely scatter them.

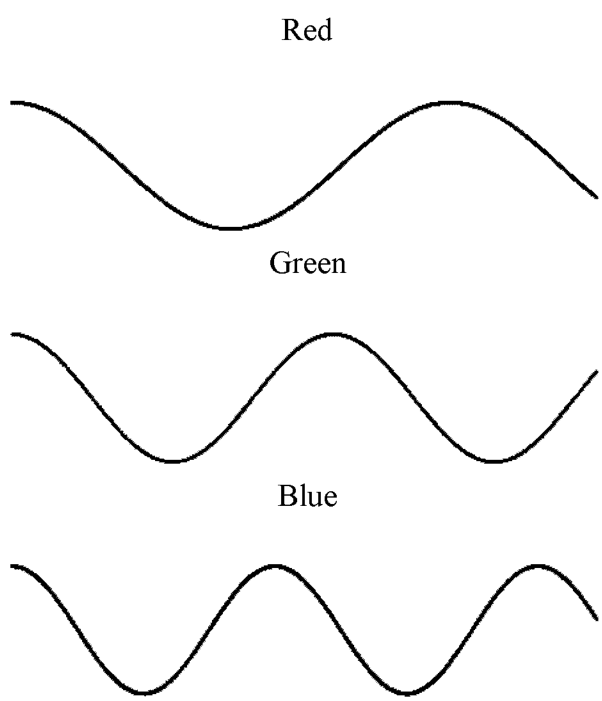

Fig. 1 – Relative Wave Length of Red, Green and Blue

This theory of the nature of light was satisfactory until it was found that it was possible by dividing a beam of light and slightly lengthening the path of one of the halves, and then reuniting the two halves together again, to produce alternate periods of darkness and light similar to the nodes of rest produced in an organ pipe, where the interference of the waves of sound is taking place. It could not be imagined that a reinforcement of one stream of particles by another stream of particles in the same direction could produce an absence of particles, while the analogy of sound suggested that just as sound was known to consist of waves in the air, so light also consisted of waves.

VIOLET	BLUE	BLUE GREEN	GREEN	YELLOW ORANGE	RED
400	450	500	550	600	700

Fig. 2 – Simple Arrangement of Spectrum

Light cannot consist of waves in the air, partly because we know that it travels through interstellar space, where we imagine that there is no air but through which we can still see the light of the stars, and also because the velocity of light - nearly 200,000 miles per second - is so great that it is impossible that it could consist of a wave in any material substance with which we are acquainted. It is, therefore, assumed that there exists, spread through all space and all matter, something in which the waves of light are formed, and this something is termed ether, so that it is generally held that light consists of waves in the ether.

Just as in sound we have wave notes of high frequency, that is, with many waves per second falling upon the ear. which form the high pitched notes, and also notes of low frequency where only a few waves a second fall upon the ear forming the bass notes, so with light we may have different frequencies of vibration. Since the velocity of light is the same for waves of different frequencies, it is clear that the waves of high frequency will be of different wave length from those of low frequency, the wave length being the distance from the crest of one wave to the crest of the next, and if we obtain waves of different lengths separated out, we shall find that the color depends upon the wave length. Fig. 1 – Relative Wave Length of Red, Green and Blue shows the average length of wave corresponding to light of various colors, the diagram being drawn to scale.

White light consists of mixtures of waves of various lengths, but if instead of letting the, mixture of waves, which forms white light, fall directly on the eye we pass white light through an instrument known as a spectroscope, which changes the direction of the different waves by amounts which differ according to their lengths, we get the white light spread out into a band of colors which we call the spectrum, and we can scale this spectrum by means of numbers representing the lengths of the waves.

Fig. 2 – Simple Arrangement of Spectrum gives a simple arrangement of the spectrum, the numbers representing the wave lengths in units which are millionths of millimeters. It will be seen that the visible spectrum extends from 700 to 400 units, wave lengths of 700 units corresponding to the extreme red and 400 to the darkest violet that can be seen, while the brightest region of the spectrum stretches from 500 to 600 units and includes the green and yellow colors. The spectrum is equally divided into three regions which may be broadly termed - red 700-600, green 600-500, and blue-violet 500-400.

If we get a piece of colored glass which lets through only the portion of the spectrum between 600 and 700, then we should have a piece of red glass; a glass which let through from 500 to 600 would be a green glass, and one which let through from 400 to 500 would be blue-violet in color, so that from the spectrum we already derive the idea that light can be conveniently divided into three colors, which we may call the primary colors - red, green and blue-violet. It is probable that this is connected with the structure of the retina, and one theory holds that there are three sets of receiving nerves in all parts of the retina, corresponding to the three primary colors - red, green and blue-violet.

If we let white light fall upon anything, such as a piece of white paper, which reflects all the wave lengths to the same extent, then the reflected light remains white and we should say that the object on which it falls is uncolored, but if the object absorbs some of the wave lengths of the spectrum more than others, then it will appear colored. Thus, a piece of red paper appears red because from the white light falling upon it it absorbs some of the green and blue-violet light, but reflects all the red light and, therefore, appears red. In the same way a green object absorbs both red and blue-violet more than it absorbs the green light and so looks green, and a yellow object absorbs the blue, reflecting the red and green of the spectrum and so appears yellow.

Light waves differ not only in their length but in their amplitude, that is, in the height of the wave, and the amplitude controls the intensity of the light just as the wave length controls the color. The eye, therefore, can detect differences in brightness which depend upon amplitude, and also differences of color which depend upon wave length.

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The camera obscura consisted of a box with a lens at one end and a ground glass at the other, just like a modern camera. It was used by artists to make a picture of anything they wanted to draw, as by observing the picture on the ground glass they could draw it more easily. Wedgwood tried to make pictures in his camera obscura by putting his prepared paper in the place of the ground glass. His paper however, was too insensitive to obtain any result; but Sir Humphrey Davy, who continued Wedgwood's experiments, using chloride of silver instead of nitrate, succeeded in making photographs through a microscope by using sunlight. These are apparently the first pictures made by means of a lens on a photographic material.

But all these attempts of Wedgwood and Davy failed because no method could be found for making the pictures permanent. The paper treated with silver chloride or silver nitrate was still sensitive to light after part of it had darkened, and if it were kept it soon went dark all over and the picture was lost. Davy concluded his account of the experiments by saying: "Nothing but a method of preventing the unshaded parts from being coloured by exposure to the day is wanting to render this process as useful as it is elegant."

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The results were very beautiful, but these early processes of photography required very great exposures so that at first the unfortunate subject had to sit for as long as ten minutes in the full sun without moving in order to impress the plate sufficiently. Although many experiments were made in an attempt to find substances more sensitive to light so that the exposure could be reduced, the only real solution was to find some method by which light had to do only a little of the work and the production of the image itself could be effected by chemical action instead of by the action of the light.

A great step in this direction was taken by Fox Talbot in 1841. He found that if he prepared a sheet of paper with silver iodide and exposed it in the camera he got only a very faint image, but if after exposure he washed over the paper with a solution containing silver nitrate and gallic acid, a solution from which metallic silver is very easily deposited, then this solution deposited the silver where the light had acted and built up the faint image into a strong picture. This building up of a faint image or, indeed, of an image which is altogether invisible, into a picture is what is now called "'development". If we expose a film in the Kodak and then, after the shutter has allowed the light to act for a fraction of a second on the film, look at the film in red light, which will not affect it, we shall not be able to see any change in the film. But if we put the film into a developing solution, the invisible image which was produced by light, and which in photographic books is called "the latent image" will be developed into a black negative representing the scene that was photographed.

Fox Talbot was not only the first to develop a faint or invisible image; he was also the first man to make a negative and use it for printing. What is meant by a negative is this: If we look at our film after we have exposed and developed it, we shall find that the sky, which was bright in the picture, is shown in our film as very black,while any shadows in the picture, which, of course, were dark, will be transparent in the film, so that the light let through the film is in the reverse order of the scene photographed, all the bright parts in the scene being dark in the film and the dark parts bright. For this reason the film is called a "negative," and when it is printed on paper the same reversal happens again and the clear parts in the negative become dark in the print while the dark parts of the negative protect the paper from the action of the light, so that the print which we may call a "positive," represents the scene as it appeared.

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All this difficulty in working disappeared with the coming of the gelatine emulsion process, which is the one now used. The sensitive coating on films and papers now consists of a bromide or chloride of silver held in a thin sheet of gelatine, the gelatine being dissolved in hot water, the silver salt formed in the solution, and the warm solution of gelatine containing silver then coated on the film or paper.

The gelatine solution with the silver in it is called an "emulsion" because of the way in which the silver remains suspended in the gelatine. The first gelatine emulsions were made in 1871 by Dr. Maddox. An emulsion made in much the way that we use now was first sold in 1873 by Burgess. At first the early experimenters made and sold the emulsion itself, drying it for sale so that photographers had to take this dried emulsion, melt it up in hot water, and coat it on their plates. After a time, however, people realized that this was a great deal of trouble and that there was no reason why the manufacturer of the emulsion should not coat the glass plates with it, and sell the ready prepared plates. In those days all negatives were made on glass plates. These plates were coated with the emulsion by hand and then when the emulsion was spread over them were put on to cold level slabs for the jelly to set before drying. Glass plates are cumbersome and heavy, and for this reason George Eastman continually experimented to substitute a light, flexible support for the brittle and heavy glass. As already mentioned, he first used paper as a support for the negative, waxing it to make it transparent for printing. This was followed by a paper from which the film carrying the image was stripped, the film being transferred to a glass plate coated with gelatine so that this gelatine made a support for the film.

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Chapter II – Light and Vision

Light is the name which we give to the external agency which enables us to see. In order to see things we must have something which enters the eye and a brain to explain it to us. That which enters the eye is what we call light.

The eye consists of two principal parts and can best be understood by analogy with the camera. In front it has a lens which forms an image on the sensitive surface, which is called the retina, the retina playing the same part in the eye that the film does in the camera. The retina, however, differs from the film in that when light falls upon the film it produces a permanent change, which can be developed into a picture, and if the light falls upon the film for too long a time the film is spoiled, while the retina merely acts as a medium to transmit to the brain the sensation of the light that falls upon it, and when the light stops, the sensation stops and the retina is ready to make a new record. The retina behaves, in fact, like a film in which the sensitive material is continually renewed.

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But the eye not only perceives differences in the brightness of the light - it also observes differences in colour - and in order to understand how this can be we must search further into the nature of light itself.

The nature of light has long been a source of speculation, and at one time it was generally held that the light which entered the eye consisted of small particles shot off from the source of light, just as at one time it was held that sound consisted of small particles shot off from the source of a sound which struck the drum of the ear. This theory of light has the advantage that it immediately explains reflection; just as an india rubber ball bounces from a smooth wall, while it will be shot in almost any direction from a heap of stones, so the small particles of light would rebound from a polished surface at a regular angle, while a rough surface would merely scatter them.

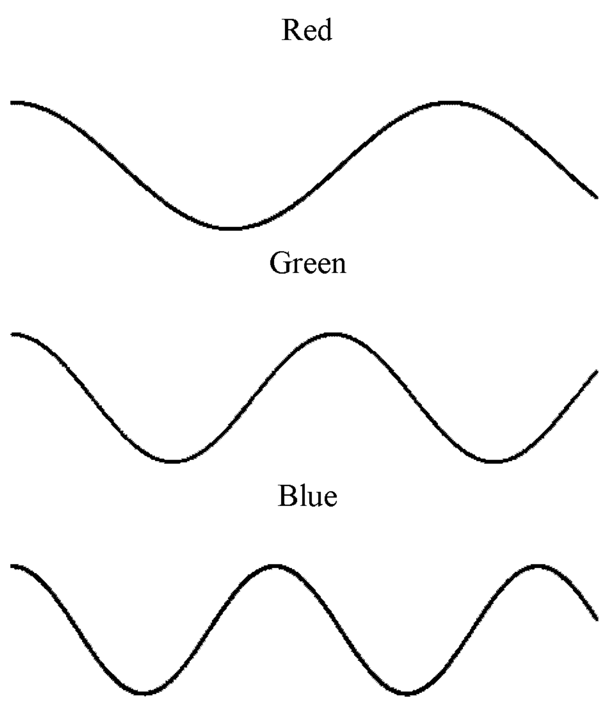

Fig. 1 – Relative Wave Length of Red, Green and Blue

This theory of the nature of light was satisfactory until it was found that it was possible by dividing a beam of light and slightly lengthening the path of one of the halves, and then reuniting the two halves together again, to produce alternate periods of darkness and light similar to the nodes of rest produced in an organ pipe, where the interference of the waves of sound is taking place. It could not be imagined that a reinforcement of one stream of particles by another stream of particles in the same direction could produce an absence of particles, while the analogy of sound suggested that just as sound was known to consist of waves in the air, so light also consisted of waves.

VIOLET	**BLUE**	**BLUE GREEN**	**GREEN**	**YELLOW ORANGE**	**RED**
400	450	500	550	600	700

Fig. 2 – Simple Arrangement of Spectrum

Light cannot consist of waves in the air, partly because we know that it travels through interstellar space, where we imagine that there is no air but through which we can still see the light of the stars, and also because the velocity of light - nearly 200,000 miles per second - is so great that it is impossible that it could consist of a wave in any material substance with which we are acquainted. It is, therefore, assumed that there exists, spread through all space and all matter, something in which the waves of light are formed, and this something is termed ether, so that it is generally held that light consists of waves in the ether.

Just as in sound we have wave notes of high frequency, that is, with many waves per second falling upon the ear. which form the high pitched notes, and also notes of low frequency where only a few waves a second fall upon the ear forming the bass notes, so with light we may have different frequencies of vibration. Since the velocity of light is the same for waves of different frequencies, it is clear that the waves of high frequency will be of different wave length from those of low frequency, the wave length being the distance from the crest of one wave to the crest of the next, and if we obtain waves of different lengths separated out, we shall find that the color depends upon the wave length. Fig. 1 – Relative Wave Length of Red, Green and Blue shows the average length of wave corresponding to light of various colors, the diagram being drawn to scale.

White light consists of mixtures of waves of various lengths, but if instead of letting the, mixture of waves, which forms white light, fall directly on the eye we pass white light through an instrument known as a spectroscope, which changes the direction of the different waves by amounts which differ according to their lengths, we get the white light spread out into a band of colors which we call the spectrum, and we can scale this spectrum by means of numbers representing the lengths of the waves.

Fig. 2 – Simple Arrangement of Spectrum gives a simple arrangement of the spectrum, the numbers representing the wave lengths in units which are millionths of millimeters. It will be seen that the visible spectrum extends from 700 to 400 units, wave lengths of 700 units corresponding to the extreme red and 400 to the darkest violet that can be seen, while the brightest region of the spectrum stretches from 500 to 600 units and includes the green and yellow colors. The spectrum is equally divided into three regions which may be broadly termed - red 700-600, green 600-500, and blue-violet 500-400.

If we get a piece of colored glass which lets through only the portion of the spectrum between 600 and 700, then we should have a piece of red glass; a glass which let through from 500 to 600 would be a green glass, and one which let through from 400 to 500 would be blue-violet in color, so that from the spectrum we already derive the idea that light can be conveniently divided into three colors, which we may call the primary colors - red, green and blue-violet. It is probable that this is connected with the structure of the retina, and one theory holds that there are three sets of receiving nerves in all parts of the retina, corresponding to the three primary colors - red, green and blue-violet.

If we let white light fall upon anything, such as a piece of white paper, which reflects all the wave lengths to the same extent, then the reflected light remains white and we should say that the object on which it falls is uncolored, but if the object absorbs some of the wave lengths of the spectrum more than others, then it will appear colored. Thus, a piece of red paper appears red because from the white light falling upon it it absorbs some of the green and blue-violet light, but reflects all the red light and, therefore, appears red. In the same way a green object absorbs both red and blue-violet more than it absorbs the green light and so looks green, and a yellow object absorbs the blue, reflecting the red and green of the spectrum and so appears yellow.

Light waves differ not only in their length but in their amplitude, that is, in the height of the wave, and the amplitude controls the intensity of the light just as the wave length controls the color. The eye, therefore, can detect differences in brightness which depend upon amplitude, and also differences of color which depend upon wave length.