THE OPTICS OF PHOTOGRAPHY.

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

The material Universe forms one vast system, a whole, in which no part can exist in a state of isolation from the rest. It is impossible to bring any influence to bear upon one of them without affecting everything else. When Newton saw the apple fall, the train of thought suggested to his mind began its effect upon the thought of all succeeding time; while the change produced in the earth's center of gravity by the change of the apple's position affected not only the planets on the very outskirts of our system but even the remotest of the fixed stars. So also every branch of physical science necessarily affects every other branch, insomuch that it is impossible to study one and exclude the rest. We cannot become proficient in physics without a knowledge of chemistry, nor in chemistry without a knowledge of physics. All sciences are mutually indebted to each other, and all profit by discoveries in any one of them

Fig. 1.

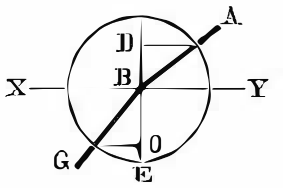
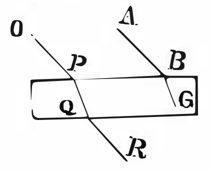
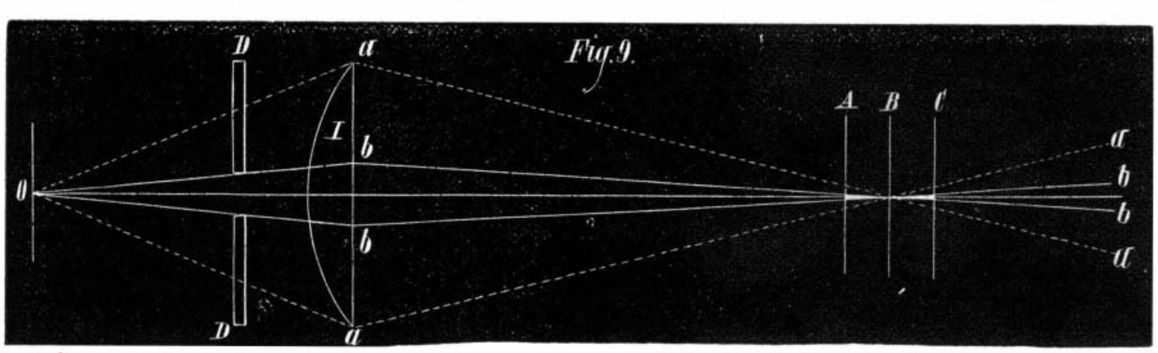


Fig 2



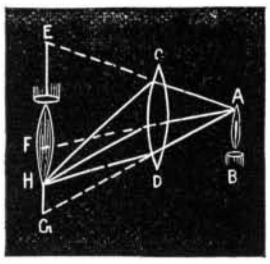
In the subject of the present lecture, we have an example of the interdependence of optics and chemistry. Photography owes perhaps its origin to the science of optics; but it soon made good its indebtedness by originating, in its turn, considerable advances in practical optics.

In the latter half of the fifteenth century, the camera obscura was invented by Baptista Porta, and certainly no one who ever beheld the image produced in this well known instrument could help a feeling of regret that it was not permanent, and a desire to make it so. Thus did the invention of this optical instrument give the first impulse in the direction of photography.



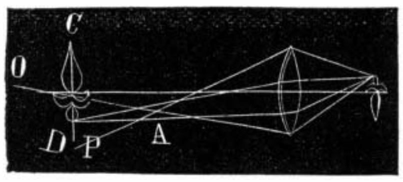
When Daguerre had solved the problem of fixing the image of the camera obscura, his chemical discovery immediately reacted upon optical science. Chemistry called upon optics for the means of producing an image so accurate and perfect in all respects as to be worthy of that permanence, of that immortality which she could confer. This was the great problem in practical optics of the day, as will be readily conceded after an explanation of what was required, what were the difficulties, and how thoroughly they have been vanquished. This problem and its solution originated and now constitutes the science of photographic optics or the optics of photography.

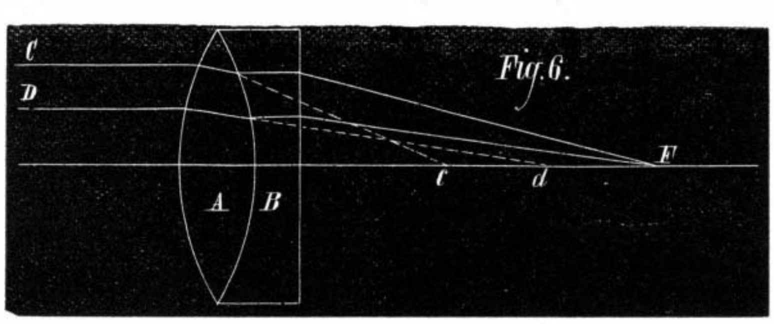
Fig. 3.



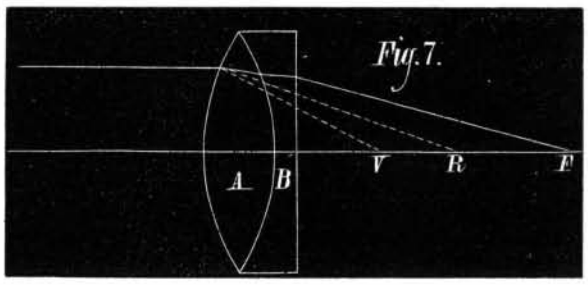
To obtain a proper appreciation of the question, it will be well to begin at the very beginning. When a ray of light passes from a rarer to a denser medium, as for example from air into glass, its course is changed by being bent towards the line perpendicular to the entering surface. On passing from glass into air, it is bent in the opposite direction. In Fig. 1 the upper half of the circle, above X Y, is a rarer and the lower half a denser medium. The ray, A B, is bent in the direction, B G. The amount of this bending or refraction varies with the nature of the substances employed, and is found by dividing the sine of the angle of incidence by the sine of the angle of refraction. In Fig. 2, let Q G be a bar of glass; then the ray, O P, will be deflected on entering the prism by being bent towards the perpendicular; while on leaving it again and passing into the air, it will be bent as much away from the perpendicular, and will consequently emerge parallel to its original direction.

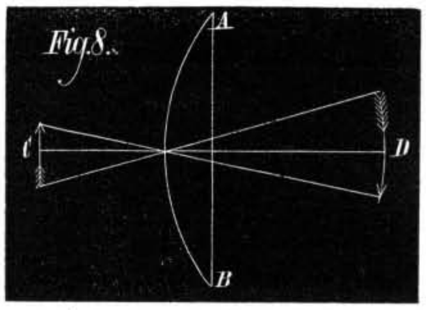
Fig. 5.

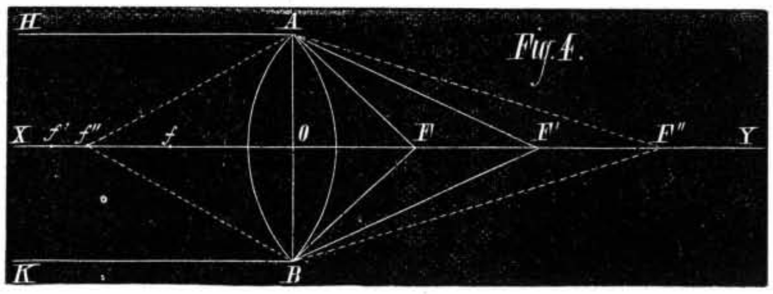




This principle was beautifully shown by projecting an arrow on the screen and then interposing a bar of glass between a part of it and the rays. The result was that, where the rays were intercepted by the glass, the arrow was broken and the broken piece stood either above or below the rest, according to the inclination of the glass. Now if the intercepting glass is made in the form of a lens, all the rays striking it from any one luminous point will be refracted to a point on the other side of the lens, because it is made up of a number of prisms, the angles of whose surfaces grow more acute as we pass from the center to the ends, C and D, Fig. 3. In this figure we have three out of many rays striking the lens from A; by carefully constructing the passage of these rays, it is found that they will all meet in the point, H. The same can be shown with any other point of the candle, A B; so that if a screen were placed at E G, we would obtain a reversed image of the candle.







Passing now from this general statement to the principles involved, we find that parallel rays, falling on an ordinary glass lens having both surfaces of the same curvature, will meet in the center of curvature on the other side of the lens. Thus, in Fig. 4, the rays, H A, K B, will be refracted to the point, F. The same would be true for any other parallel rays not drawn in the figure, because they would be acted on equally by the opposite surfaces of the lens; and they would be bent less and less the more we approached the middle of the lens, because the angle decreases more and more. The point, F, is called the focus, a word meaning fireplace. Conversely all rays, starting from F, would emerge parallel on the other side of the lens.

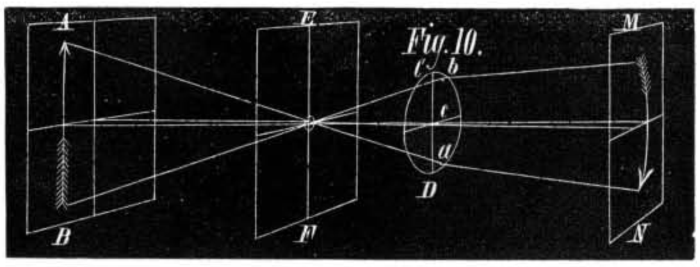
If now we suppose the lens split in half in the direction, A O B, and one half removed, its converging power would evidently be reduced one half; in other words, the focus will be twice as far off, and the rays, H A, K B, will now be bent only to F'. Conversely, rays starting from F' will emerge parallel. Now, if we put the other half of the lens on again, rays starting from F' will converge at f', just as far on the other side of the lens. It is evident, moreover, that, the further the source of rays is removed from F', in the direction F' Y, the less their divergence, and the easier it is for the lens to make them converge on the other side. Hence the further we put the source of light from the lens on one side, the nearer the lens will its rays be brought to a focus on the other side. Thus the point, F'', corresponds to j''. Conversely, rays proceeding from j'' will diverge so much that the lens can bring them to a focus only at F''. Two points having such relations to each other are called conjugate foci.

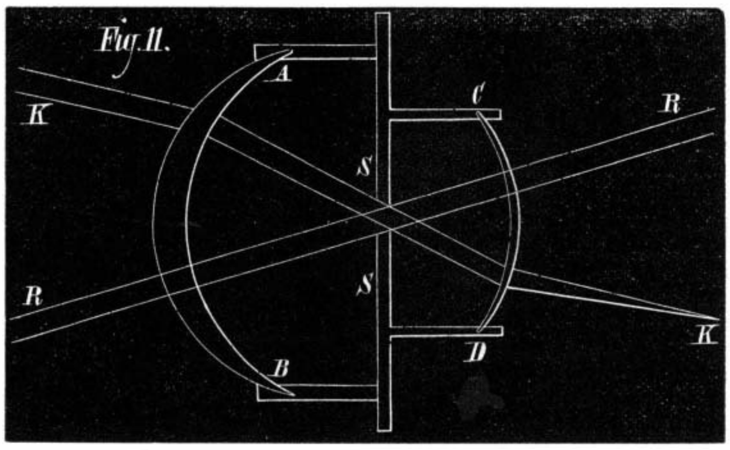
To illustrate this, the lecturer had a lens and a burning candle on the stage. Placing the candle at a proper distance from the lens, an image of it was produced on the screen. When the candle was then brought nearer the lens, it was found necessary to move the lens further from the screen to get an image; and when the candle was further removed from the lens, the latter had to be placed near the screen. It was also observed that, the nearer the candle was to the lens, the larger the image produced.

Unfortunately it is impossible, even with the most skillful workmanship, to construct spherical lenses, which bring objects to a perfectly sharp focus. This is especially the case with large lenses. Thus rays coming from the bottom of the inverted object, in Fig. 5, will not all meet in the same point. Those passing through points near the center will meet at D; those passing through the ends will come to A; and intermediate rays will assume positions between these two points, so that a blurred image results. This error is called spherical aberration.

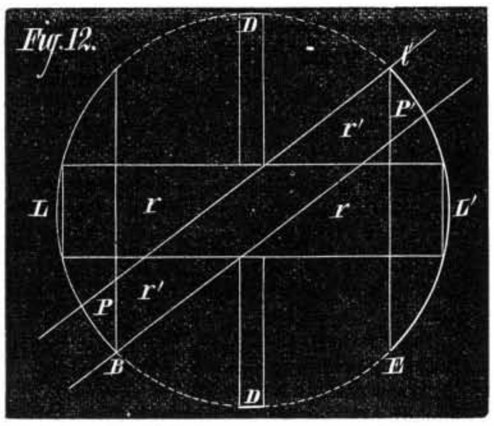
This defect is corrected by joining to our double convex lens another having one surface concave and the other plane, as in Fig. 6. The refraction is greatest near the points of the lens, A, because the angle between its two surfaces is greatest there; on adding the lens, B, however, which acts in the contrary direction, the rays are lifted up most near the ends of the lens, just where they need it most, and a compensation is thus effected. By the use of the lens, A, alone, the ray, C, would pass to *c*, and the ray, D, to *d*; on adding the lens, B, however, both will converge at F.

Another source of error lies in the fact that the rays of light are of different refrangibility; so that the red rays will pass to one, and the violet to the other, end of a band called the spectrum, in which the other colors occupy intermediate positions. Now, as these different rays possess different photographic power, we would obtain an image of varying intensity. This is called chromatic aberration. To correct this defect, a similar arrangement is employed as in the case of spherical aberration. It has been found that some kinds of glass possess a greater power of dispersion, that is, of separating the rays of different colors, than others. Taking advantage of this property, the lens, B, Fig. 7, is made of heavy lead glass, having a high dispersing power. With the lens, A, alone, the ray, S, would have been separated into a series of colors stretching from V to R; but on passing through B, they undergo a reversing process, and are brought to a focus at F. Either lens alone would produce a chromatic aberration; but placed together they correct each other because they act in opposite directions.





A third source of error is what is known as the curvature of the field. It is evident, on inspecting Fig. 8, that rays of the same length, passing from an object, C, through the optical center of the lens, A B, will not form a flat, but a curved, image. If, therefore, a flat screen is placed at D, the top and bottom of the arrow will be out of focus; and if the screen is properly placed for the top and bottom of the arrow, the middle will be out of focus. The different parts of the image evidently do not lie in the same plane; and to correct this error, the same device will have to be employed as in photographing at the same time objects lying in several different planes more or less distant from each other. In other words, we must produce what is known as "depth of focus." This is necessary even in taking a portrait, where the nose and the ears of the sitter, for example, would come to a focus at different distances from the lens.



The depth of focus is increased by means of the diaphragm or stop, an ingenious contrivance, shown at D D, in Fig. 9, by which all rays coming from an object at O are cut off, with the exception of those passing through the opening. Without the stop, the outer rays, O *a*, would diverge considerably on both sides of the focal point cut by the screen, B; and if this screen were moved to the position, A or C, the curvature of the resulting image would become very appreciable. With the stop, however, the screen could be moved anywhere between A and C, and a tolerably sharp image produced.

It is not possible, however, by the use of the diaphragm alone to correct the curvature of the field entirely. The effect of the diaphragm is really to divide the lens into as many little lenses as there are pencils of light passing through it. Some of these pass through the ends of the lens where there is greater converging power, and are consequently brought to a nearer focus than those passing through the middle. This circumstance of itself would tend to produce a distortion. This is shown in Fig. 10, where the parts of the arrow, A B, not lying in the axis of the lens, C D (and consequently obliged by the diaphragm, E F, to pass through the ends of the lens, at *a* and *b*), are brought to a focus nearer the lens than the middle points.

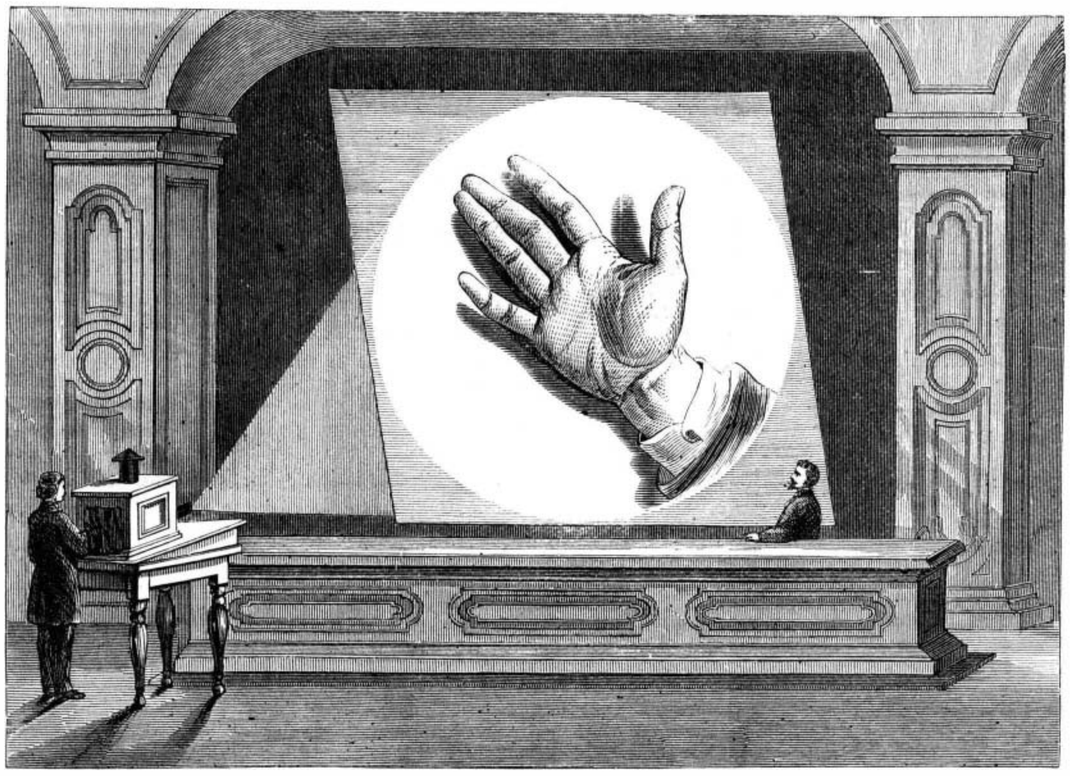


Fig. 13.—THE MEGASCOPE.

It has been found by experience that a convergent meniscus lens provided with a stop and placed with its concave side toward the object to be photographed, will produce the least amount of curvature of the field. When the convex side is turned towards the object, a greater curve is produced in the opposite direction. Hence, by combining two such meniscuses, and placing a diaphragm between them at the proper relative distance from the lenses, this fault is entirely overcome. These and other considerations, which would take us too far, led Mr. Zentmayer, of Philadelphia, to invent his celebrated lens, a representation of which is given in Fig. 11. Here we have two meniscuses, A B and C D, with a stop, S S, nearer the smaller one. The lenses are made of the same kind of glass, and yet counteract each other's errors so well as to produce a very perfect instrument. The leading principles will be better understood from the following drawings: In Fig. 12, let A B represent two plano-convex lenses, exactly alike, and so placed that their outer surfaces form parts of an imaginary sphere, A B C D. Then, neglecting refraction for a moment, it is evident that a bundle of rays, r r, which the aperture of the diaphragm, D D, allows to pass through both lenses, will be affected only by the little lenses, L, L′, and two blocks of glass having parallel surfaces. Hence, we will get only the insignificant amount of spherical and chromatic aberration due to two minute lenses. The rays, r' r', passing through the edges of the lenses, A B and C D, will be affected only by the two prisms, P and P′, which will counteract each other, being exactly equal and opposite. For the reason already stated, and on account of the refraction of the rays, the diaphragm is not placed in the center, but a little to one side. This instrument has a most remarkable depth of focus, and produces most excellent results.

To show that any refracting medium, water for example, could become a lens when made into the proper shape, the lecturer placed a watch glass in the path of the rays coming from a vertical lantern containing a slide of a fine piece of statuary. Nothing was visible on the screen, until he poured water into the watch glass, when the image came out with surprising distinctness. The applause which followed this striking experiment sufficed to agitate the water, disturbing the shape of the lens and destroying the image, which did not perfectly reappear until the water came to rest.

One of the most astonishing effects that a lens is capable of producing was shown by the aid of an instrument called the megascope, represented in Fig. 13. This is nothing more than a dark box, having a lens in front and illuminated inside with an oxycalcium light falling on a sheet of white paper in the rear of the box. When the hand is held as close to the light as it can be without burning it, an immense image in natural colors and startling relief is produced on the screen. The huge proportions of this mammoth hand produced a ludicrous effect when compared with the hand of an assistant standing near the screen. Other objects, such as a plaster cast, a mother of pearl shell, an apple cut in half, and the works of a watch, were then shown with splendid effect. The images of these objects are so large that it is difficult to keep them in focus in all their parts. The lecturer concluded by exhibiting a number of photographs upon the screen, pointing out their artistic excellence and defects in accordance with the principles laid down.

C. F. K.

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Facts and Simple Formulæ for Mechanics, Farmers, and Engineers.

[We are constantly receiving letters, asking for simple rules for various engineering and mechanical operations. Frequently the writers send us merely the problem, requesting us to apply the rule and publish the solution. In order to avoid repetition, it is our custom to refer correspondents, presenting analogous cases, to those already published in these columns, leaving them to apply the information there given to their own wants. In deference to the demand for the rules abstractly stated, and believing that in many instances a reference to the rule itself rather than to any application of it will serve our correspondents' purpose better and at the same time relieve our already crowded query columns, we shall from time to time present a series of useful facts and formulæ taken from the works of Molesworth, Haswell, Nystrom, "Wrinkles and Recipes," and other reliable sources, in place of our usual collection of recipes. Brief and simple rules, which are the results of the experience of any of our readers, we shall be glad to receive for publication in this connection; and correspondents sending us queries on any mechanical or engineering subject, answerable by rules or formulæ, will generally here find the information needed.—EDS.]

Shrinkage of castings, in locomotive cylinders $\frac{1}{16}$ inch in a foot; in pipes $\frac{1}{8}$ inch in a foot; girders, beams, etc., $\frac{1}{8}$ inch in 15 inches; engine beams, connecting rods, etc., $\frac{1}{8}$ inch in 16; thin brass $\frac{1}{8}$ inch in 9; thick brass $\frac{1}{8}$ inch in 10; in zinc $\frac{5}{16}$ inch in a foot; in lead, same; in copper $\frac{3}{16}$ inch in a foot; in bismuth $\frac{5}{32}$ inch in a foot; in tin $\frac{1}{4}$ inch in a foot.

To test iron and steel: Nitric acid will produce a black spot on steel; the darker the spot, the harder the steel. Iron, on the contrary, remains bright if touched with nitric acid. Good steel in its soft state has a curved fracture and a uniform gray luster; in its hard state, a dull silvery uniform white. Cracks, threads, or sparkling particles denote bad quality. Good steel will not bear a white heat without falling to pieces, and will crumble under the hammer at a bright red heat; while at a middling heat it may be drawn out under the hammer to a fine point. To test the toughness, place the fragment on a block of cast iron; if good, it may be driven by a blow of a hammer into the iron; if poor, it will be crushed under the blow.

Main shafting in woodworking shops should run at 300 revolutions per minute. Mortising machines, 250 to 300 strokes per minute; stroke 6 to 9 inches. Sharpening angle for machine cutters, adzing soft wood across the grain, 30°; ordinary soft wood planing machines, 35°; gouges and plowing machines, 40°; hard wood tool cutters, 50° to 55°.

The hide of a steer weighs about the eighteenth part, and the tallow the twelfth part, of the living animal.

The buoyancy of a cask in lbs. = 10 times the capacity in gallons *minus* the weight of the cask itself.

A square of slate or slating is 100 superficial feet. The lap of slates varies from 2 to 4 inches. The pitch of a slate roof should not be less than 1 inch in hight to 4 inches in length.

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Wood Ashes.

On another page we publish illustrations of the effects of potassa and other chemical fertilizers on potato and grape vines. The most accessible and cheapest form in which potassa is obtainable is wood ashes, which every country housekeeper should carefully collect from the hearth. Mr. Austin P. Nichols, of the Boston *Journal of Chemistry*, has recently made some analyses of ashes taken from the hearth, with the following potassa results:

	No. 1.	No. 2.	Mean.
Potassa..................	12·55	12·64	12·59
Carbonate of potassa......	18·38	18·55	18·48

"The wood from which the ashes came consisted of a mixture of hickory and beech. The results show the amount of pure potassa and carbonate of potassa which the ashes contained; but the absolute alkali power and value as represented are best shown in the amount of crude or commercial potassa held in the ashes. One hundred lbs. held 19·85 lbs. of alkaline salts, soluble in water, and consequently, if we estimate the value of commercial potassa at eight cents per pound, we have a cash potassa value in these ashes of $8.60 in each 100 lbs. A bushel of dry ashes weighs about 34 lbs.; this would give a potassa value to each bushel of fifty-three cents. The ordinary ashes, such as are collected in the country by soap boilers, are usually not so rich in alkaline constituents. The mean potassa value of these ashes, estimated upon the value here adopted, we have found to be about forty-two cents per bushel. From these results it is clear that the farmer had better retain his ashes for farm use than to sell them at the price usually obtained from soap peddlers. Besides the potassa salts, ashes contain important amounts of phosphoric acid, soluble silica, etc., which add greatly to their value as fertilizing material. It is safe to say that every bushel of true wood ashes which a farmer produces upon his hearth is worth to him, for farm use, forty cents in gold. It is, therefore, very poor husbandry to sell them for twenty cents the bushel, as many do. We value ashes so highly that offers for them are rejected, no matter what they may be.

"In the mixture of raw bone meal and ashes, recommended by us ten years ago, we get quite all the valuable constituents of plant food, and at cheaper rates than in any other mixtures. We have used this combination for many successive seasons, with most satisfactory results. We confidently expect that the German potassa products will before long stop the consumption of wood ashes in the manufacture of American potassas, and it will be a happy day for our agricultural industry, if the products of our wood fires are turned in the direction of the farm."

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RED INK.—The following recipe for a beautiful red ink is given by Metra, of Paris: Dissolve 25 parts, by weight, of saffranin in 500 parts warm glycerin, then stir in carefully 500 parts alcohol and an equal quantity of acetic acid. It is then diluted with 9,000 parts water, in which is dissolved a little gum arabic.

Inventions Patented in England by Americans.

[Compiled from the Commissioners of Patents' Journal.]

From May 24 to June 7, 1876, inclusive.

AIR GUN.—I. Johnson *et al.*, Worcester, Mass.
ATMOSPHERIC HAMMER.—J. C. Butterfield, Chicago, Ill.
BANK CHECK, ETC.—J. B. Johnston, New York city.
BEER TAP.—G. C. Driner *et al.*, Brooklyn, N. Y.
BILLIARD BALL.—W. H. Lippincott, Pittsburgh, Pa.
BOILER.—I. Barton, Williamsport, Pa.
BOMB LANCE.—P. Cunningham, Newark, N. J.
BOOT HEEL TRIMMER.—L. Graf, Newark, N. J.
CIGAR LIGHTER.—O. W. Boyden, Newark, N. J., *et al.*
CURTAIN FIXTURE.—C. Buckley *et al.*, Meriden, Conn.
DESK.—W. S. Wooton, Indianapolis, Ind.
ENVELOPE.—H. Burnell, San Francisco, Cal.
FARE REGISTER.—A. Hance *et al.*, New York city.
FIBER DRAWING HEAD.—J. Good, Brooklyn, N. Y.
HARVESTER.—B. F. Jackson, Pittsfield, Ill.
HECKLING HEMP, ETC.—J. Good, Brooklyn, N. Y.
LOOM.—G. Crompton, Worcester, Mass.
MAKING GAS.—T. S. Stewart, Philadelphia, Pa.
MAKING WOOD SCREWS.—T. J. Sloan, New York city.
MOTIVE ENGINE, ETC.—J. T. Gallup, Greenport, N. Y.
PANTALOONS.—G. R. Eagar, Boston, Mass.
PIPE-CUTTING TOOL.—A. Saunders, Yonkers, N. Y.
POLISHING BUTTONS.—G. P. Warner, Leeds, Mass.
ROCK DRILL.—J. B. Waring, New York city.
ROCK DRILL.—W. W. Dunn (of San Francisco, Cal.), London, England.
SWIMMING APPARATUS.—R. B. Pumphrey, Baltimore, Md.
TREATING REFUSE OIL, ETC.—W. P. Jenney, New York city.
WASHING FABRICS.—J. Brown, Monticello, N. Y.
WASHING WOOL, ETC.—F. G. Sargent, Graniteville Mass