XEROGRAPHY

A Newcomer to the Graphic Arts

by CHESTER F. CARLSON

IT WAS IN ABOUT 600 B. C. that Thales of Miletus discovered that if amber were rubbed with a piece of silk it strongly attracted bits of lint, straw and other materials. Today this phenomenon is being applied to the processes of printing, duplicating, copying, and photographing—with some surprising results.

Imagine, for instance, a printing plate consisting of a smooth metal sheet on which the image to be printed is formed of an insulating material affixed to its surface. If the image is given an electrostatic charge by frictionally rubbing the plate with a cloth or brush, or by passing the plate under a corona discharge electrode, it will electrostatically pick up an ink powder. The portion of the metal plate forming the background for the image will remain clean.

The powder electrostatically held on the insulating image can then be transferred to a sheet of paper held against the plate, by simply spraying an electric charge on the paper with the corona discharge electrode. The image can be permanently affixed to the paper with a solvent, or by heating to fuse the powder onto the sheet.

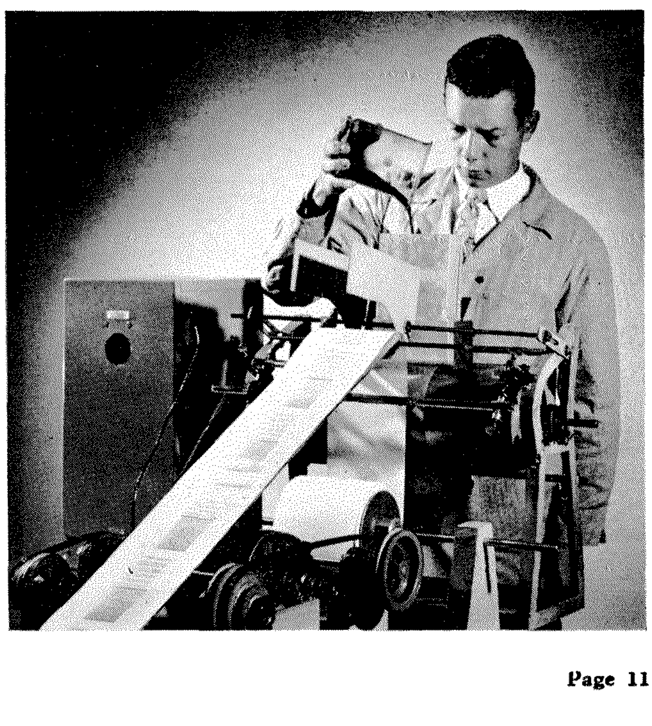
The steps can be repeated any number of times to produce a large number of copies, the same printing plate being used repeatedly. And since the steps are all mechanical in nature, they can be performed automatically by a suitably designed printing press.

This, in brief, is a description of Xeroprinting, one branch of a family of new graphic arts processes known collectively as Xerography (pronounced Zeer-aw'-graphy). Other members of the family are Xeroduplicating and Xerocopying.

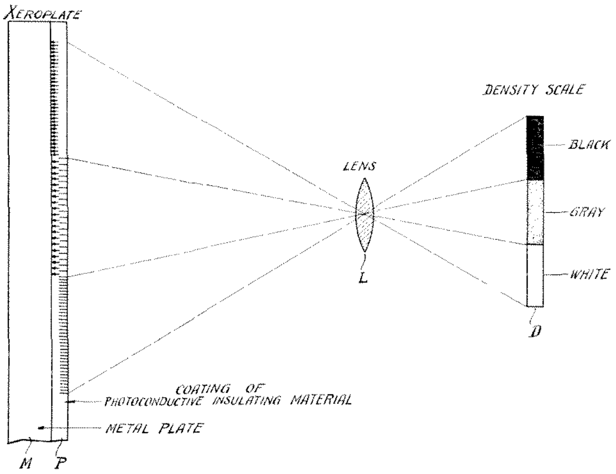
Xerography in all its phases is now the subject of an extensive research project at Battelle Memorial Institute, Columbus, Ohio and is commercially sponsored by The Haloid Company of Rochester, New York. The processes are based on patented inventions of the author.

The Xeroprinting process, like other printing procedures, is intended for the commercial printing field, to fill the need for rapid production of large numbers of identical copies. Where smaller runs are needed, with the minimum amount of equipment, the process can be adapted to office duplicating as a Xeroduplicating process.

There are many situations, however, where the number of copies required is so small that the cost of preparing a printing plate, or a duplicating-machine master plate, would be prohibitive. How many times have you needed just one or two extra copies of a letter, specification, drawing or memorandum? You've probably had to get a photocopy, or a blueprint, or resort to a complete retyping of manuscript material. Xerocopying is intended to fill this need. It uses a



Dry printing is one of the potential uses of Xerography. With this experimental printing press, engineers at the Battelle Memorial Institute in Columbus, Ohio, have already achieved a press speed of 1200 feet a minute. Besides speed, chief advantages of Xeroprinting will be the light weight of printing machinery and simplicity of plate-making.



HOW XEROGRAPHY WORKS

A specially-coated metal plate is given an electric charge, and placed in a camera. An image—in this case a density-scale chart—is focused on the surface (P) of the plate by the camera lens. When light reaches the plate, the electric charge drains off the surface to the metal backing (M). Arrows show how the charge disappears completely from the white area, partly from the gray, not at all from the black.

dry electrostatic method, as in Xeroprinting, but with a light-sensitive photo-electric plate, known as a Xeroplate, intead of the Xeroprinting plate described.

A better understanding of the Xerographic process may be obtained by reference to the diagrams on this page. The Xeroplate comprises a metal backing sheet (plate M in the diagram above) carrying a thin layer (P) of a "photoconductive insulating material" a few ten thousandths of an inch thick. Sulphur is one suitable photoconductive insulating material. Anthracene is another. Vitreous selenium also falls in this class, but not the metallic form.

Most engineers are familiar with selenium photoelectric cells. The operation of one type of cell depends upon the increase in electrical conductivity of a layer of metallic selenium when it is illuminated. But even in the dark such cells have a substantial conductivity. The photo-conductive insulating materials used for Xerography are of much higher insulating value than metallic selenium—their resistance in the dark being comparable to that of other good insulators. Sulphur, in fact, is one of the best insulators known, having a resistivity in the order of 10^{17} ohm-cm.

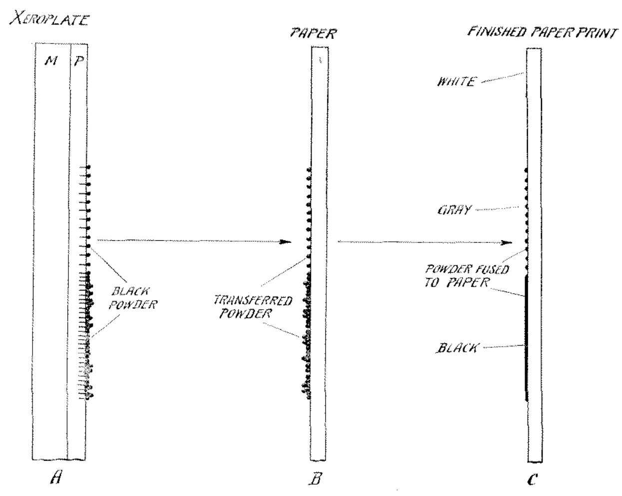
Thin layers of sulphur, anthracene, selenium, and other photoconductive insulating materials have the property of being rendered instantaneously more conductive upon exposure to light. Dr. A. L. Hughes and Caltech's Dr. L. A. DuBridge, in their excellent and very complete reference text **Photoelectric Phenomena,** mention that Joffé has reported that the conductivity of sulphur can be increased a million-fold by illumination. This would reduce its resistivity from 10^{17} to 10^{11} ohm-cm.—still a rather high resistance! Investigations so far indicate that the response to illumination of these photoconductive insulating materials is instantaneous, and is proportional to the intensity of the light for any given wave length. As soon as the illumination is cut off, the material instantaneously returns to its dark insulating value. The behavior differs in this respect from that of metallic selenium photoelectric cells, in which the conductivity builds up gradually after the light is turned on, and decays gradually after it is cut off.

A more complete explanation would be that the conductivities involved in Xerography are of a much lower order than those utilized in photo-cells, and while these instantaneous primary currents may also be present in photo-cells, they are masked by the superposed "secondary" currents arising from the primary currents in such cells.

Now, having indicated the nature of the Xeroplate, we can consider further the process of Xerography as applied to Xerocopying. If the coating of photoconductive insulating material of the Xeroplate is given a uniform electrostatic charge over its surface it is ready for exposure. This can be performed by placing it in a camera and focusing an image on the surface of the plate, as indicated in the diagram above.

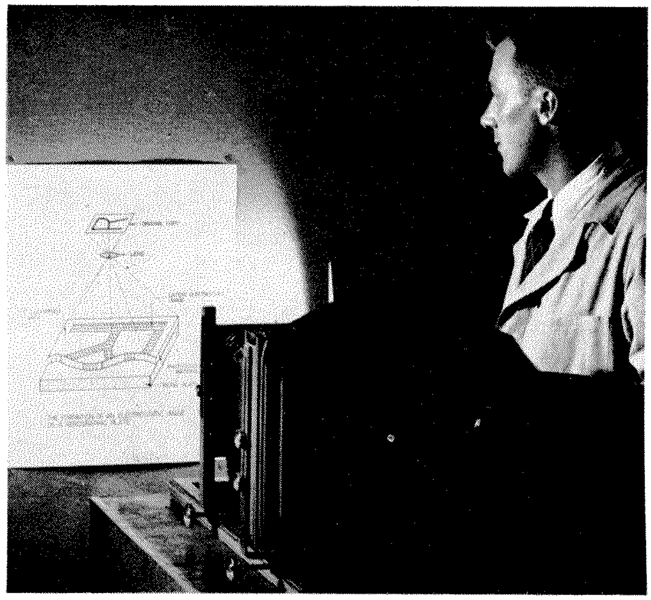
MAKING A XEROPRINT

The exposed Xeroplate (A), which now bears a "latent" image of the density scale (see diagram at top of page) is coated with a dry, black powder. The powder adheres to the charged—black and gray—areas of the plate. Then, when a sheet of charged paper is held against the plate, the powder is transferred to it. Quick heating fuses the powder to the paper, and produces a permanent, fixed print.



For convenience of explanation let us assume that we are making a Xerocopy of the density scale (D). The scale may be simply a sheet of cardboard having three areas, the uppermost of which is black, the middle area being gray and the lower end of the strip being white. The image of the black area is focused by the lens (L) on the lower end of the Xeroplate. Since practically no light comes from this part of the density scale, the lower portion of the plate remains substantially in darkness, and the electric charge which is held on its surface is undisturbed—as indicated by the minus signs in layer P.

In the middle area, where the gray portion of the density scale is focused, sufficient light reaches the plate to render the insulating layer slightly conductive during exposure. This allows part of the electrostatic charge we have placed on its surface to drain off, through the photoconductive insulating layer, to the metal backing—as indicated by the small arrows. The result is that a reduced electrostatic charge is left on this area after exposure.



Above:

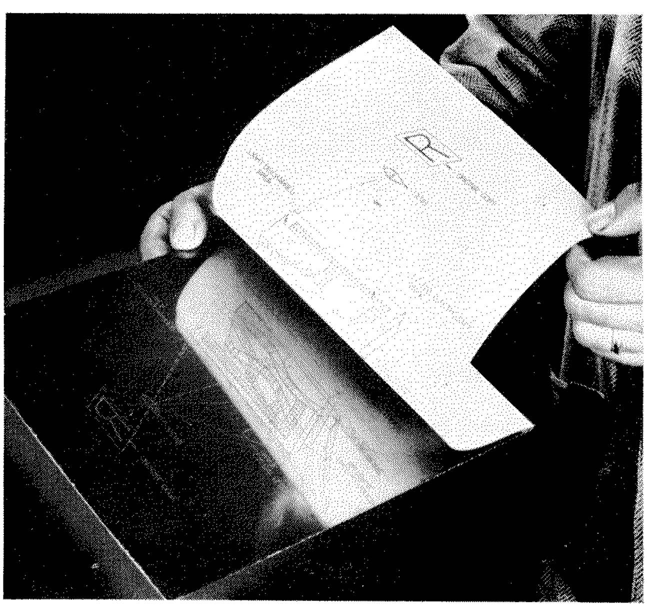
Exposing Xeroplate in camera.

Left:

Developing plate by cascading powder over surface.

Below:

Stripping transferred print from plate.



The upper part of the plate, on which the white area of the cardboard is focused, receives so much light that nearly all of the charge is conducted away, leaving this area almost completely discharged. We now have on the Xeroplate an "electrostatic latent image" of the cardboard density scale.

The plate is then removed from the camera in a closed plate holder and a fine black powder is applied to its surface in a covered tray. When the excess powder is removed, it will be found that powder adheres to the charged areas of the plate by electrostatic attraction, substantially in proportion to the "blackness" of the areas of the density scale. Thus, the part of the plate which received the image of the black area of the density scale will be completely covered with a layer of powder. The area corresponding to the gray part of the scale will be covered with a less-dense distribution of powder particles. And the area which received the image of the white part of the scale will retain practically no powder.

The developed Xeroplate is indicated at A in the diagram at the bottom of page 12. If a sheet of paper is now placed against the surface of the plate carrying the powder image and the assembly passed under a corona discharge wire, the powder will be transferred to the paper as indicated at B.

Suitable black or colored powders can be used for development, but for convenience in obtaining a permanent copy it is desirable to use a powder which can be permanently affixed to the paper. A satisfactory developing powder can be formed from certain fusible resins which are naturally black or colored, or which have been dyed or pigmented to provide any desired color. After transfer to the paper the sheet is heated momentarily to fuse the powder onto the surface of the paper, thus completing the Xerocopy as indicated at C.

Instead of using a camera, the plate can be exposed in a contact printing frame by placing a transparent original—a film, a sheet of tracing paper carrying a drawing, or a typewritten letter—directly against the surface and exposing to an incandescent lamp or other light source. Exposure can also be effected by projecting an image onto the plate with a projector or enlarger.

Either a negative or a positive electric charge may be applied to the plate prior to exposure. With frictional charging the sign of the charge is dependent

Camera portraits of live subjects, like that at left, can be taken by the Xerographic process. Finished prints are ready within 45 seconds after exposure. Though quality of photographs is not too satisfactory yet, the Haloid Co. of Rochester, N. Y., plans eventually to develop a good Xerocamera.

upon the triboelectric properties of the material which is rubbed against the surface of the plate. With corona charging the sign is dependent upon the polarity of the corona electrode. A dusting powder is selected so as to give the best results with the polarity of the charge used.

Black areas of the original are reproduced as black (or colored) areas on the copies. Hence a direct positive is obtained from the original without the necessity of first making a negative. Positives from negatives are also possible. With camera exposure, or contact printing in which the face of the original is placed against the plate, the right-hand edge of the original comes out as the right-hand edge of the copy, so that the copy reads the right way, rather than as a mirror reverse.

For the Xerographic portrait above the subject sat in front of a camera containing a Xeroplate. An exposure was made, the plate developed with black powder, and the powder image then transferred to, and affixed on, a sheet of paper.

Of course the picture you see here, like the other illustrations in this magazine, was prepared for printing in ENGINEERING AND SCIENCE by conventional methods. Briefly, these involve exposing a layer of bichromated gelatin, or similar photosensitive covering, on a metal plate to form a hardened gelatin image. After washing away the hardened gelatin to leave a resist image, the plate is chemically etched to remove part of the metal and leave raised printing surfaces.

Xerography may some day supplant these involved procedures and make practicable the direct production of printing plates for conventional printing processes, as well as for Xeroprinting, by a method requiring only a single exposure step. One way in which this can be done is to transfer the resin powder image obtained on the Xeroplate to a clean metal plate, and then fuse the powder onto the metal to produce the resist image for etching to make a printing plate.

Another method of making printing plates, which requires no transfer of the powder, is made possible by the properties of certain of the coatings used for Xeroplates. One of these photoconductive coatings is anthracene, a waxlike insulating material derived from coal tar. It can be evaporated or sublimed readily by moderate heating. Hence, when the powder image has been deposited on the anthracene coating after exposuse of the plate, it is only necessary to heat the plate to evaporate the anthracene, and then raise the temperature sufficiently to fuse the resin powder onto the metal backing layer. The metal can then be etched in acid to produce a printing plate. Lithographic plates can be prepared by quite similar procedures, using grained zinc or aluminum plates.

Several other applications of Xerography are being developed. An office copying machine has been designed which will turn out copies of letters, drawings, and other documents in a few seconds—from the start of operations until the finished copy is obtained.

The stenographer of the future may not be concerned with carbon paper. She can simply type the original letter, slip it into a Xerocopying machine, set a dial for the number of copies desired, push a button, and the required number of clean permanent copies will issue from the machine in a few seconds.

The color possibilities of Xerography are intriguing. Since there is no limitation on the colors of the dusting powders which may be used, it is possible to obtain a copy of any color desired. By using a colored paper sheet to receive the image a two-color print may be produced. Multiple color prints and natural color photographs have been obtained by a series of independent exposures for each color. The powder images of each color are all transferred to a single sheet of paper, where they are superimposed in correct register to form the multi-color image.

Many fields of application for the various phases of Xerography remain to be further explored. They range from the purely pictorial applications, through the various copying and office duplicating processes, to the commercial printing field. A few of its potential applications include the making of murals, billboards, and wallpaper—economically. Its versatility may even make it a valuable tool in many new fields not adequately served by present known procedures.