How Laser Printers Work

by Tom Harris

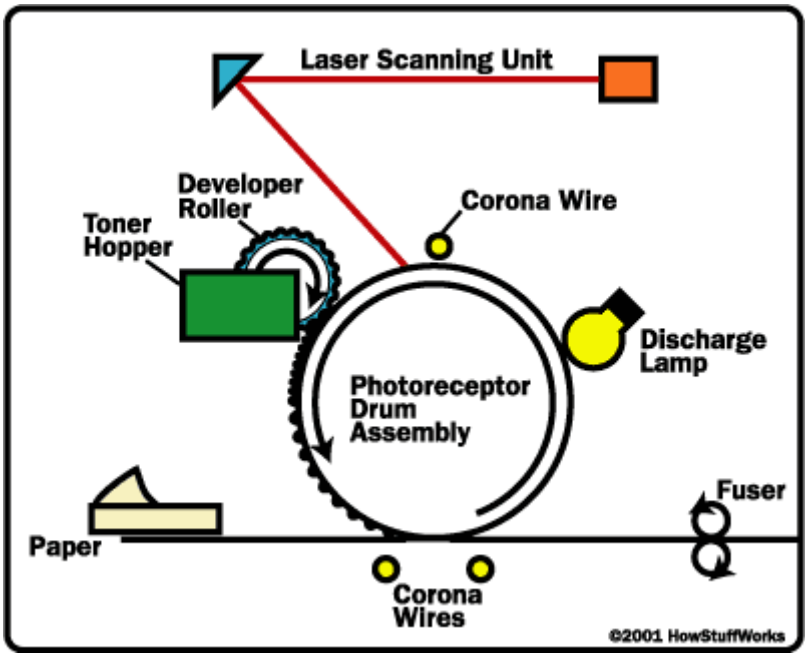
The term inkjet printer is very descriptive of the process at work -- these printers put an image on paper using tiny jets of ink. The term **laser printer**, on the other hand, is a bit more mysterious -- how can a laser beam, a highly focused beam of light, write letters and draw pictures on paper?

Hewlett Packard LaserJet 4050T

In this article, we'll unravel the mystery behind the laser printer, tracing a page's path from the characters on your computer screen to printed letters on paper. As it turns out, the laser printing process is based on some very basic scientific principles applied in an exceptionally innovative way.

The Basic Process

The primary principle at work in a laser printer is static electricity, the same energy that makes clothes in the dryer stick together or a lightning bolt travel from a thundercloud to the ground. Static electricity is simply an electrical charge built up on an **insulated object**, such as a balloon or your body. Since oppositely charged atoms are attracted to each other, objects with opposite static electricity fields cling together.



The basic components of a laser printer

A laser printer uses this phenomenon as a sort of "temporary glue." The core component of this system is the **photoreceptor**, typically a revolving drum or cylinder. This **drum assembly** is made out of highly **photoconductive** material that is discharged by light photons.

Initially, the drum is given a total **positive charge** by the **charge corona wire**, a wire with an electrical current running through it. (Some printers use a **charged roller** instead of a corona wire, but the principle is the same.) As the drum revolves, the printer shines a tiny laser beam across the surface to discharge certain points. In this way, the laser "draws" the letters and images to be printed as a pattern of electrical charges -- an **electrostatic image**. The system can also work with the charges reversed -- that is, a positive electrostatic image on a negative background.

The laser "writes" on a photoconductive revolving drum.

After the pattern is set, the printer coats the drum with positively charged **toner** -- a fine, black powder. Since it has a positive charge, the toner clings to the negative discharged areas of the drum, but not to the positively charged "background." This is something like writing on a soda can with glue and then rolling it over some flour: The flour only sticks to the glue-coated part of the can, so you end up with a message written in powder.

With the powder pattern affixed, the drum rolls over a sheet of paper, which is moving along a belt below. Before the paper rolls under the drum, it is given a negative charge by the **transfer corona wire** (charged roller). This charge is stronger than the negative charge of the electrostatic image, so the paper can pull the toner powder away. Since it is moving at the same speed as the drum, the paper picks up the image pattern exactly. To keep the paper from clinging to the drum, it is discharged by the **detac corona wire** immediately after picking up the toner.

Finally, the printer passes the paper through the **fuser**, a pair of heated rollers. As the paper passes through these rollers, the loose toner powder melts, fusing with the fibers in the paper. The fuser rolls the paper to the output tray, and you have your finished page. The fuser also heats up the paper itself, of course, which is why pages are always hot when they come out of a laser printer or photocopier.

So what keeps the paper from burning up? Mainly, *speed* -- the paper passes through the rollers so quickly that it doesn't get very hot.

After depositing toner on the paper, the drum surface passes the **discharge lamp**. This bright light exposes the entire photoreceptor surface, erasing the electrical image. The drum surface then passes the charge corona wire, which reapplies the positive charge.

Conceptually, this is all there is to it. Of course, actually bringing everything together is a lot more complex. In the following sections, we'll examine the different components in greater detail to see how they produce text and images so quickly and precisely.

The Controller

Before a laser printer can do anything else, it needs to receive the page data and figure out how it's going to put everything on the paper. This is the job of the **printer controller**.

The printer controller is the laser printer's main onboard computer. It talks to the host computer (for example, your PC) through a communications port, such as a parallel port or USB port. At the

start of the printing job, the laser printer establishes with the host computer how they will exchange data. The controller may have to start and stop the host computer periodically to process the information it has received.

A typical laser printer has a few different types of communications ports.

In an office, a laser printer will probably be connected to several separate host computers, so multiple users can print documents from their machine. The controller handles each one separately, but may be carrying on many "conversations" concurrently. This ability to handle several jobs at once is one of the reasons why laser printers are so popular.

For the printer controller and the host computer to communicate, they need to speak the same **page description language**. In earlier printers, the computer sent a special sort of text file and a simple code giving the printer some basic formatting information. Since these early printers had only a few fonts, this was a very straightforward process.

These days, you might have hundreds of different fonts to choose from, and you wouldn't think twice about printing a complex graphic. To handle all of this diverse information, the printer needs to speak a more advanced language.

The primary printer languages these days are Hewlett Packard's **Printer Command Language** (PCL) and Adobe's **Postscript**. Both of these languages describe the page in **vector** form -- that is, as mathematical values of geometric shapes, rather than as a series of dots (a **bitmap** image). The printer itself takes the vector images and converts them into a bitmap page. With this system, the printer can receive elaborate, complex pages, featuring any sort of font or image. Also, since the printer creates the bitmap image itself, it can use its maximum printer resolution.

Some printers use a **graphical device interface** (GDI) format instead of a standard PCL. In this system, the host computer creates the dot array itself, so the controller doesn't have to process anything -- it just sends the dot instructions on to the laser.

But in most laser printers, the controller must organize all of the data it receives from the host computer. This includes all of the commands that tell the printer what to do -- what paper to use, how to format the page, how to handle the font, etc. For the controller to work with this data, it has to get it in the right order.

Once the data is structured, the controller begins putting the page together. It sets the text margins, arranges the words and places any graphics. When the page is arranged, the **raster image processor** (RIP) takes the page data, either as a whole or piece by piece, and breaks it down into an array of tiny dots. As we'll see in the next section, the printer needs the page in this form so the laser can write it out on the photoreceptor drum.

In most laser printers, the controller saves all print-job data in its own memory. This lets the controller put different printing jobs into a **queue** so it can work through them one at a time. It also saves time when printing multiple copies of a document, since the host computer only has to send the data once.

The Laser

Since it actually draws the page, the printer's laser system -- or **laser scanning assembly** -- must be incredibly precise. The traditional laser scanning assembly includes:

- A **laser**
- A **movable mirror**
- A **lens**

The laser receives the page data -- the tiny dots that make up the text and images -- one horizontal line at a time. As the beam moves across the drum, the laser emits a pulse of light for every dot to be printed, and no pulse for every dot of empty space.

The laser doesn't actually move the beam itself. It bounces the beam off a movable **mirror** instead. As the mirror moves, it shines the beam through a series of **lenses**. This system compensates for the image distortion caused by the varying distance between the mirror and points along the drum.

The laser assembly moves in only one plane, horizontally. After each horizontal scan, the printer moves the photoreceptor drum up a notch so the laser assembly can draw the next line. A small **print-engine computer** synchronizes all of this perfectly, even at dizzying speeds.

Some laser printers use a strip of **light emitting diodes** (LEDs) to write the page image, instead of a single laser. Each dot position has its own dedicated light, which means the printer has one set print resolution. These systems cost less to manufacture than true laser assemblies, but they produce inferior results. Typically, you'll only find them in less expensive printers.

Photocopiers

Laser printers work the same basic way as photocopiers, with a few significant differences. The most obvious difference is the source of the image: A photocopier scans an image by reflecting a bright light off of it, while a laser printer receives the image in digital form.

Another major difference is how the electrostatic image is created. When a photocopier bounces light off a piece of paper, the light reflects back onto the photoreceptor from the white areas but is absorbed by the dark areas. In this process, the "background" is discharged, while the electrostatic image retains a positive charge. This method is called "write-white."

In most laser printers, the process is reversed: The laser discharges the lines of the electrostatic image and leaves the background positively charged. In a printer, this "write-black" system is easier to implement than a "write-white" system, and it generally produces better results.

Toner

One of the most distinctive things about a laser printer (or photocopier) is the toner. It's such a strange concept for the paper to grab the "ink" rather than the printer applying it. And it's even stranger that the "ink" isn't really ink at all.

So what is toner? The short answer is: It's an electrically-charged powder with two main ingredients: **pigment** and **plastic**.

The role of the pigment is fairly obvious -- it provides the coloring (black, in a monochrome printer) that fills in the text and images. This pigment is blended into plastic particles, so the toner will melt when it passes through the heat of the fuser. This quality gives toner a number of advantages over liquid ink. Chiefly, it firmly binds to the fibers in almost any type of paper, which means the text won't smudge or bleed easily.

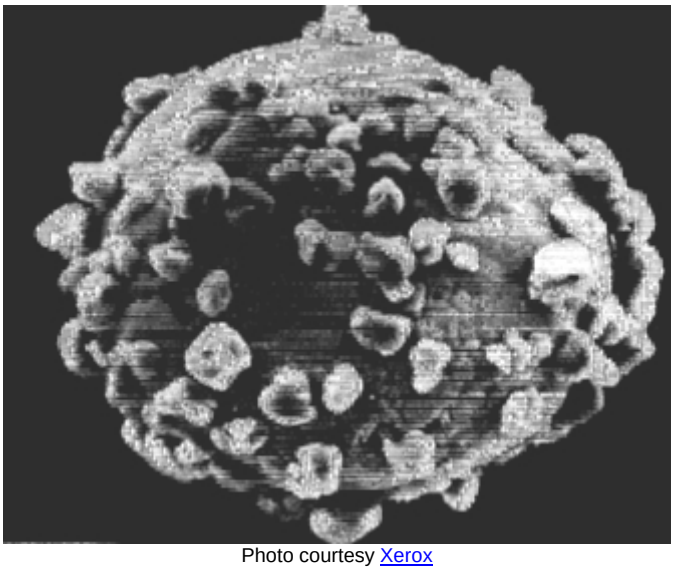


Photo courtesy Xerox

A developer bead coated with small toner particles

So how does the printer apply this toner to the electrostatic image on the drum? The powder is stored in the **toner hopper**, a small container built into a removable casing. The printer gathers the toner from the hopper with the **developer unit**. The "developer" is actually a collection of small, negatively charged magnetic beads. These beads are attached to a rotating metal roller, which moves them through the toner in the toner hopper.

Because they are negatively charged, the developer beads collect the positive toner particles as they pass through. The roller then brushes the beads past the drum assembly. The electrostatic image has a stronger negative charge than the developer beads, so the drum pulls the toner particles away.

In a lot of printers, the toner hopper, developer and drum assembly are combined in one replaceable cartridge.

The drum then moves over the paper, which has an even stronger charge and so grabs the toner. After collecting the toner, the paper is immediately discharged by the detac corona wire. At this point, the only thing keeping the toner on the page is gravity -- if you were to blow on the page, you would completely lose the image. The page must pass through the fuser to affix the toner. The fuser rollers are heated by internal **quartz tube lamps**, so the plastic in the toner melts as it passes through.

But what keeps the toner from collecting on the fuser rolls, rather than sticking to the page? To keep this from happening, the fuser rolls must be coated with **Teflon**, the same non-stick material that keeps your breakfast from sticking to the bottom of the frying pan.

Color Printers

Initially, most commercial laser printers were limited to monochrome printing (black writing on white paper). But now, there are lots of color laser printers on the market.

Essentially, color printers work the same way as monochrome printers, except they go through the entire printing process four times -- one pass each for cyan (blue), magenta (red), yellow and black. By combining these four colors of toner in varying proportions, you can generate the full spectrum of color.

Inside a color laser printer

There are several different ways of doing this. Some models have four toner and developer units on a rotating wheel. The printer lays down the electrostatic image for one color and puts that toner unit into position. It then applies this color to the paper and goes through the process again for the next color. Some printers add all four colors to a plate before placing the image on paper.

Some more expensive printers actually have a complete printer unit -- a laser assembly, a drum and a toner system -- for each color. The paper simply moves past the different drum heads, collecting all the colors in a sort of assembly line.

Advantages of a Laser

So why get a laser printer rather than a cheaper inkjet printer? The main advantages of laser

printers are speed, precision and economy. A laser can move very quickly, so it can "write" with much greater speed than an ink jet. And because the laser beam has an unvarying diameter, it can draw more precisely, without spilling any excess ink.

Laser printers tend to be more expensive than inkjet printers, but it doesn't cost as much to keep them running -- toner powder is cheap and lasts a long time, while you can use up expensive ink cartridges very quickly. This is why offices typically use a laser printer as their "work horse," their machine for printing long text documents. In most models, this mechanical efficiency is complemented by advanced processing efficiency. A typical laser-printer controller can serve everybody in a small office.

When they were first introduced, laser printers were too expensive to use as a personal printer. Since that time, however, laser printers have gotten much more affordable. Now you can pick up a basic model for just a little bit more than a nice inkjet printer.

As technology advances, laser-printer prices should continue to drop, while performance improves. We'll also see a number of innovative design variations, and possibly brand-new applications of electrostatic printing. Many inventors believe we've only scratched the surface of what we can do with simple static electricity!