about Plasmas

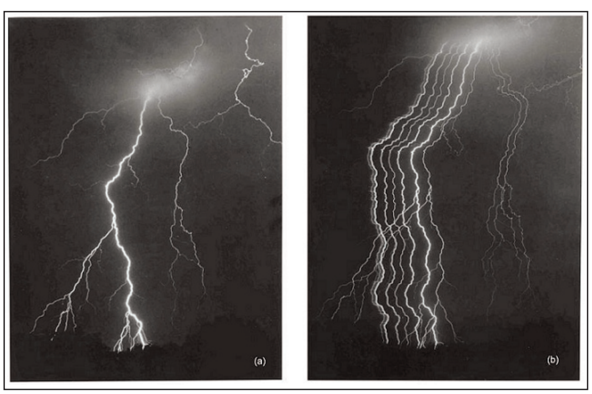
from the Coalition for Plasma Science

# Lightning

Lightning was striking the Earth long before human life began, and may even have played a crucial role in the evolution of life on our planet. Around the globe, lightning lights up the sky fifty to one hundred times per second, and while not every lightning bolt reaches the ground – about 75% of lightning discharges remain in the clouds – each year in the United States alone lightning hits the ground about twenty-five million times. While there are clearly negative aspects to such strikes, there are also unwarranted concerns and even positive aspects. Although lightning can sometimes cause significant damage, especially for unprotected people and objects, the number of people killed by lightning is small compared with other accidental causes of death. And although each commercial aircraft is struck by lightning on average once a year, it is not a significant hazard since today's airplanes are designed to handle such strikes without serious problems. Furthermore, over 30% of all electric power line failures and many forest fires are lightning-related. It is worth mentioning, however, that lightning-initiated forest fires play an important role in the natural life cycle of forests.

Lightning, a natural plasma spectacle, is a challenge to understand.

Lightning is a high-current electric discharge in air, releasing most of its energy in pulses about one-hundred-millionth of a second long. With its length measured in miles and a diameter of only one or two inches, a typical lightning bolt carries a peak current of tens of thousands of amperes and has a peak temperature greater than 50,000°F, about five times hotter than the surface of the Sun. At that high temperature the lightning column is a plasma, a gas with many of its atoms broken into electrically-charged particles, both negatively-charged electrons and positively-charged ions. Such a gas is said to be "ionized." It is the movement of those charged particles through the lightning channel – primarily the movement of electrons – that constitutes the electrical current.




All images in these photos are of the same lightning flash. The left photo (a) was taken with a stationary camera; photo (b) was taken with a camera that was moving horizontally during the flash (time advances from right to left). This is a downward flash as indicated by the downward direction of the branches. Photo (b) appears to show at least seven separate individual strokes following the same path from cloud to ground, with the first stroke being on the far right.

Lightning arises from electrical charges residing on soft hail and ice crystals that move about in the air. When positive and negative charges accumulate in separate regions, large voltages can develop between the charged regions and between one charged region and the ground. When this voltage becomes large enough – in the range of 50 to 500 million volts – the air in between may become significantly ionized and form a plasma column, the electrically-conducting channel we see as lightning.

Not all lightning develops in the same way or in the same direction. In about 90% of global cloud-to-ground lightning, negative charge is effectively transported from a cloud to the ground. This type of lightning is called "negative downward lightning." Other types of cloud-to-ground lightning include positive downward, negative upward and positive upward discharges. Lightning can extend upward from a tall grounded object such as the Empire State Building in New York or the CN Tower in Toronto. But lightning is so fast, the naked eye cannot see and appreciate its stages of development and its complex structure. And we can only determine the direction of lightning development if we can see branches extending off from the main channel.

Continued on back

A flash of lightning can consist of a number of individual strokes, each following the same path from cloud to ground. The plasma is recreated over and over again in the same channel. The dark intervals between these strokes are typically in the range of tens of milliseconds. This explains why the human eye perceives lightning as "flickering." A lightning flash typically contains three to five strokes, although the observed number of strokes ranges from one to twenty-six.

Each downward stroke is composed of a downward-moving "leader," followed by an upward-moving "return-stroke." The leader creates a conducting path between the cloud and ground and distributes negative charge from the cloud along that path; the return stroke follows the same path moving from the ground toward the cloud, distributing positive charge to neutralize the negative leader charge.

The electrical current in a lightning flash varies from stroke to stroke as well as during each stroke. The return-stroke current rises rapidly to an initial peak of tens of thousands of amperes. That initial current pulse may be followed by a current of hundreds of amperes lasting for tens of thousandths of a second. The high return-stroke current rapidly heats the channel to a peak temperature near or above 50,000°F, increasing the pressure in the channel to ten or more times normal atmospheric pressure. This makes the channel produce the intense light that we see and makes it expand, producing a shock wave that eventually becomes the thunder sound wave we hear in the distance.

Extracting useful energy from lightning appears to be impractical. First, the total energy in each cloud-to-ground lightning flash is only about 360 kilowatt-hours, approximately the energy required to operate five 100-Watt light bulbs continuously for one month. And only about one-thousandth to one-hundredth of that energy is delivered to the strike point, the bulk of the energy being lost to heating the air and producing thunder, light, and radio waves. Secondly, even if it were possible to capture all of a flash's energy, the probability of lightning striking a given point on the ground is very low. For example, a grounded 60-meter tower located in Florida is expected to be struck by lightning only once every other year. Since most of the U.S. experiences two to three times lower lightning activity than Florida, capturing lightning strikes would require an impractically large number of tall towers.

Lightning can be triggered intentionally to research and test various schemes that will help protect people and buildings. The most effective technique for inducing lightning involves launching a small rocket toward a charged cloud overhead, with the rocket trailing a thin grounded wire.

**It is common for lightning to form ground surface arcs (plasma channels) that develop horizontally outward from its ground termination point. The photograph shows surface arcing during a rocket-triggered flash. The lightning channel is outside the field of view. One of the surface arcs approaches the right edge of the photograph, a distance of 10 meters from the rocket launcher.**

Lightning is not limited to the Earth's atmosphere. There is convincing evidence for lightning-like discharges on Jupiter. Electric currents in Jupiter lightning are expected to be ten to one-hundred times larger than in Earth lightning.

While we have come to understand much about lightning, questions remain, such as concerns about high-energy radiation from lightning, which might be sufficiently intense to harm people. Also of interest are the nitrogen oxides produced during a flash, which might affect global warming. In addition, certain types of lightning, such as ball lightning, are not well understood. Further studies should produce some answers and solutions to the continuing challenges of this fascinating natural plasma.


Suggested Reading::

V. A. Rakov and M.A. Uman, Lightning: Physics and Effects, Cambridge University Press, 2003.

M.A. Uman, Understanding Lightning, Bek Technical Publications, Carnegie, PA, 1971.

J. R. Dwyer, "A Bolt Out of the Blue," Scientific American, Vol. 292, No. 5, May 2005, pp. 64-71.



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