THE DANGER

Because lightning is so spectacularly powerful, it has excited the curiosity and fear of man since the earliest times. Prof. W.R. Lee of the Department of Occupational Health, University of Manchester, explains just how dangerous lightning is.

A FLASH OF LIGHTNING comprises one or more strokes and rarely lasts more than a second. The lightning stroke generally starts in a negatively charged region of a cloud from which a 'leader-stroke' seems to proceed towards the ground in discrete steps. The electrostatic field which develops below the leader rapidly increases in strength so that, when the tip of the leader has reached a height of some tens of metres above ground level, a short upward streamer can be initiated from a vertical conductor. This might be an isolated tree, a church steeple, a tall building, the mast of a boat, or perhaps a person standing in the open with an umbrella or a golf club above his head.

When the leader makes contact with the ground, or with the short upward streamer, a 'return stroke' develops which may be imagined as a positive current flowing upwards. This may reach tens of thousands, or even one or two hundred thousand amperes.

The electrical potential involved in a lightning strike cannot at present be accurately measured, but it is believed to be about 10^6 to 10^8 volts.

OF LIGHTNING

Whatever the actual voltage, a lightning stroke can immediately puncture the skin of a victim.

More is known about the characteristics of the lightning current, at least at the point of strike. This is fortunate for physiological responses depend on the current rather than the applied voltage. Characteristic waveshapes of lightning current are unidirectional with a fast rising front and a slower tail usually lasting several tens of microseconds.

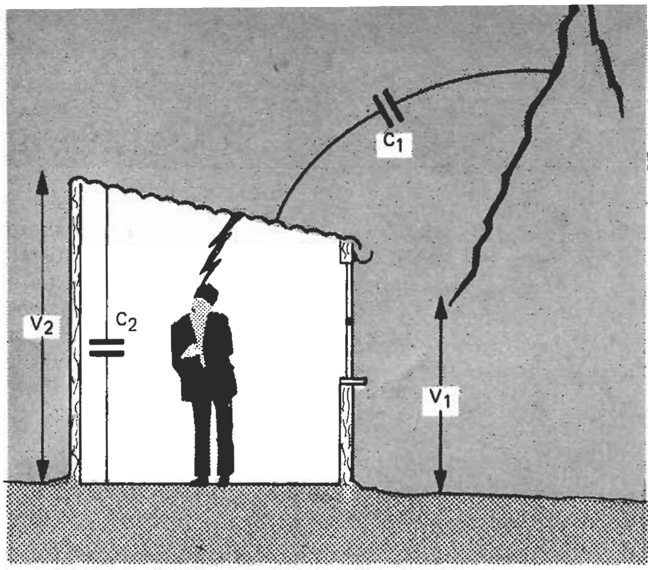
In mountainous regions conditions may be different. The bottom of a thundercloud may lie only a short distance above conducting objects, such as human beings from whom arise, as point or brush discharge, currents of several micro-amperes. These may be felt as a slight tingling, perhaps raising the hair on a bared head. At night they may appear as a luminous glow. In the past this glow, appearing at the tops of ships' masts during stormy conditions, was called St. Elmo's fire — after the patron saint of Mediterranean sailors. Such point discharges can develop into an upward-directed leader stroke which may last several tenths of a second and involve a current of some hundreds of amperes.

Four Types

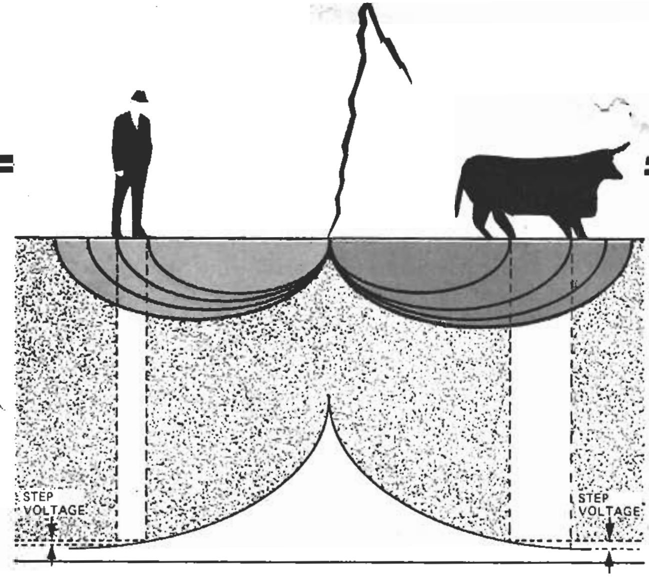
When accidents are considered, lightning strokes may be grouped in four types. A direct stroke occurs when the person or something he is holding is struck. The lightning current enters the head or upper part of the trunk, passing through the body and into the ground through the feet. If several persons are standing close together more than one may be struck.

It has been calculated that the current rises rapidly to a peak of 1 000 A (amperes), immediately falling so that about 10 microseconds from the start it reaches 4 A and remains at that value for the duration of the strike. The occurrence of an external flashover is confirmed by ample evidence from accident reports. If it occurs outside the body and through or outside the clothing, the hair and beard may be singed, there may be burn marks on the soles of the feet and burn marks are found on the clothes, which may catch fire. Metals carried on the body may melt, causing burns. If the flashover is between the body and the clothing, current flowing over the body surface may convert the sweat and skin moisture into steam so that the resulting pressure causes clothes or boots to be torn off.

The second type of lightning stroke is the side flash. This is most clearly understood by considering what happens when someone is sheltering under a tree that is struck. Standing on the ground he is initially at earth potential. However, as the lightning current discharged down the tree trunk increases, the voltage drop down the lower part of the trunk, which might have a resistance of a few kilohms, may become greater than the electrical breakdown strength of the air gap between the trunk and the person. A side flash then occurs through the victim.



Side flash from a corrugated iron roof insulated from earth by a dry wooden structure. When a lightning stroke develops nearby, the effect of the electrical capacitances represented by C_1 and C_2 is to raise the roof to a potential V_2, with respect to earth, equal to $V_1C_1/(C_1-C_2)$. The potential difference between the roof and the head of the occupant of the shed can become high enough to cause a flashover without the shed being struck.



Regular pattern (a) of current in uniformly constituted soil, set up by a direct lightning strike to open ground. The potential distribution curve (b) shows how a 'step' voltage develops between the legs of humans or animals standing nearby.

There is more than one report of persons struck while cycling past a tree. One victim who was unconscious for 15 minutes, and did not need resuscitation, subsequently recalled a 'blow' and that he saw 'fire' coming to him from the tree and that the handlebars of his bicycle 'became electric'. He sustained no burn marks. Quite a number of accidents are on record of death or injury occurring in persons sheltering in a tent, and the descriptions of the circumstances and of the injuries strongly suggest side flashes from the tent pole or perhaps from the wet fabric.

One of the most dramatic and serious accidents involving side flashes in recent times occurred in the Japanese Alps in 1967. A party of forty-one schoolchildren with five teachers was overtaken by a sudden thunderstorm when they were strung out along a steep ridge immediately below a mountain peak 1 660 metres above sea level. Lightning killed eleven of the boys instantly and most of the remainder were temporarily paralysed, burned or blinded.

The third type of lightning stroke is the step voltage. If lightning strikes open ground, either directly or through a tall object such as a tree or post, the current is discharged into the mass of the earth. On non-uniform ground the current distribution produces differing voltages according to the distance from the site of the strike. A person, or animal, walking along a radius from the site of the strike will be subject to a potential difference between the legs. It will be seen later that quadrupeds are more likely than humans to die from this because the current, flowing between the forelegs and hindlegs, traverses the heart, whereas in the human the pathway is from leg to leg and the heart escapes. When a church in France was struck during a service all the persons standing on the damp flagstones in the nave fell and could not get up for several minutes, as though their lower limbs were paralysed. But people standing in the oak choir stalls at the sides were spared, clearly because they were insulated from the ground.

The fourth type of stroke is the contact voltage, sometimes called a touch potential. It may be regarded as a particular instance of the side flash, in which the victim is actually making contact at the time of the lightning stroke. A case history from Russia about ten years ago gives a clear account of such an accident.

Two women were sheltering under a tall spruce tree which was struck during a thunderstorm. One of them, who was killed, stood with her back against the tree. Her clothing was not damaged but at the back of her head, on the right hand side, the hair was singed and ash grey in colour over an area 40 mm by 40 mm. In the centre of this the skin damage was like a small abrasion. On the tree trunk there was a longitudinal strip of damage to the bark about 40 to 60 mm wide starting near the top of the tree and stopping about 1.58 m from the ground, that is, on a level with the height of the victim. The other woman was holding on to the tree with her right hand. She lost consciousness for about 10 to 15 minutes and was unable to move or to feel her lower limbs for about two to three hours. She sustained some burning of the body down to the foot, but was discharged from hospital after two days and resumed work after ten days.

An intriguing theoretical study has concluded that anyone touching a lightning conductor when it is struck would not risk death because the current discharged through the body would be too weak. This is not an invitation to test the hypothesis by personal experiment!

How does lightning current produce death? Our knowledge comes from three main sources. Firstly, since the end of the last century, there has been a steady increase in our knowledge of how direct and alternating currents at mains frequency cause death. This is based, in a large part, on animal experiments. Secondly, there have been a few studies of the effects of impulse currents on animals. Thirdly, we have accounts of accidents ranging in quality from the anecdotal to the investigation which is fully and carefully documented from both the electrical and medical viewpoints. However, the accounts suffer from two main drawbacks. The obvious one is the absence of any quantitative electrical data and the other is that it is often difficult after an electrical accident to determine exactly why someone died.

Pathway

Lightning may be considered to produce direct effects in one of three ways: its action on the heart and respiration, and by heat. There are other indirect effects such as injuries from falls but they are not peculiar to lightning. For currents greater than a few milliamperes, the body behaves as a structureless gel or, for the electrical engineer, as a volume conductor. There is no 'preferred' pathway along which the current flows. It is believed that the body resistance along the path taken by the current in most direct lightning strokes, many side flashes and many contact voltage accidents, is about 500 to 1 000 ohms, possibly falling to the first value after the skin has been punctured. Generally, the effects are produced by direct action on the organs concerned, so it is important to trace the current's pathway through the body.

Careful examination of burn marks usually provides information on the points of entry and exit. Sometimes these may be surprisingly small. The lightning return stroke has a central core with a diameter of a centimetre or so, which may reach a temperature of about 30 000° K, but only for the first tens of microseconds. This may save a person from extensive burning, although small metal objects on the clothing may melt. Because the skin has the highest resistance to the current, heat tends to be developed there, often causing relatively small skin burns. But if the lightning current has a long 'tail' it may have a value of several hundred amperes during that period. This so-called 'hot' lightning can cause more severe burning of the body and clothing. Examination of victims frequently reveals 'tree-like' or aborescent markings that are not true burns. They disappear after a few hours.

Lightning current causes death by affecting either the heart or the nervous mechanism controlling respiration. The heart has two main pumping chambers — one to pump blood around the body and the other to pump it through the lungs. The thick walls of these ventricles consist almost entirely of muscle, and the simultaneous contraction of all the individual muscle fibres provides the necessary pumping pressure. An electrical current passing through the heart may disturb the concerted action of the fibres so that they contract individually and fail to establish enough pressure. When seen in this state the ventricles, instead of showing forceful regular contractions, are flaccid, with irregular twitchings (fibrillation) of the individual fibres.

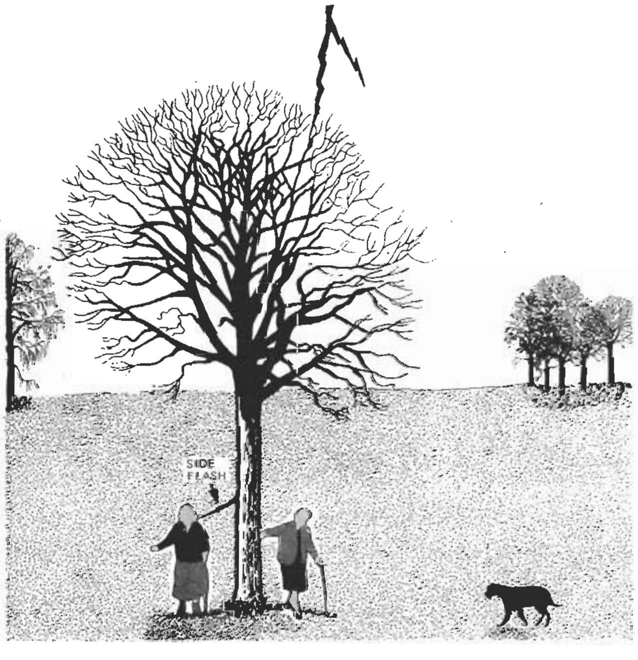
Relationships

Nearly all the investigations to establish the relationships between some electrical factor and time have been carried out using alternating current at mains frequency. The shortest duration studied in such investigations is about eight milliseconds, corresponding to a half wave at 60 Hz. This approaches that of a lightning current with a long tail.

A number of relationships have been suggested. They all accept that current, or a derivative, is important. One of the most widely published relationships suggests that within certain time limits the ventricular fibrillation threshold depends on energy. Another suggestion is that it depends on charge. One theory is that the threshold is a function simply of current but that there are in fact two thresholds, one when the current lasts for less than a heart cycle and another, much lower, if it is more (about 400 to 1 000 milliseconds).

Lightning currents do not last longer than a heart cycle. However, an electrical current will cause fibrillation only if it falls at a certain time in the cycle, the 'T' wave, which occupies about 20 to 25 per cent of the full cycle. Once fibrillation has become established, blood circulation ceases and death follows. Finally, it has recently been stated that in many victims of lightning stroke the heart simply stops altogether — ventricular asystole. First-aid treatment for both is the same.

Side flash from a tree struck by lightning. At first the current flows through the trunk. The electrical resistance of the trunk, between ground and a point level with the head of anyone standing nearby, may be a few kilohms. Build-up of current through it may cause the potential drop across the lower part of the trunk to exceed the electrical break-down strength of the air between the trunk and the victim. At that stage a side flash occurs.



Nervous System

The centre for the control of respiration by the nervous system is in the lower part of the brain. There is strong evidence that the current has to go through it to stop respiration. Indeed, in so-called electric shock treatment for certain mental disorders it is extremely uncommon for respiration to remain stopped once the current has ceased to flow. There are a number of carefully reported cases in which high voltage or lightning currents passing through the respiratory centre have caused breathing to stop. Some victims have responded to prompt artificial respiration. A current pathway through the head and trunk seems to be more common in lightning than in electric shock accidents.

Using our knowledge of how death is caused by lightning, we can attempt to establish a rational basis for first aid. Simply stated, the victim's breathing or circulation — or both — might have stopped. No first-aid manoeuvre is likely to start either again, though fortunately respiration often starts spontaneously after an interval of anything from a few seconds to several hours. Obviously, except in cases of very short arrest, it is necessary to provide artificial respiration, by first-aid and later perhaps in hospital, until breathing starts again. First-aid treatment for arrested circulation is, according to many authorities, not without serious dangers and should not be lightly undertaken. It would be prudent to learn from national first-aid organizations how these conditions may be diagnosed and treated.

Several simple precautions would reduce lightning accidents. An upright person acts like a lightning conductor and thus attracts a lightning strike over a distance which, as a first approximation, is proportional to the square of his height above the ground. It is, therefore, much safer to squat down than to stand up or, worse still, to stand on the top of a vehicle or structure. To increase one's effective height by carrying an umbrella or golf clubs, held upright, is foolish: better to get wet than killed. The risk of side flashes can be minimized by keeping at a distance of a few metres from other people when in a group, by *not* standing near the trunk of an isolated tree and by keeping away from large metallic objects both indoors and outdoors. Tents can be readily protected but it is a wise precaution to keep the greatest possible distance away from the tent pole or the wet fabric. ETI