PD IEC/TR 60479-4:2011

BSI Standards Publication

# Effects of current on human beings and livestock

## Part 4: Effects of lightning strokes



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## National foreword

This Published Document is the UK implementation of IEC/TR 60479-4:2011. It supersedes PD IEC/TR 60479-4:2004 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee JPEL/64, Electrical installations of buildings – Joint committee.

A list of organizations represented on this committee can be obtained on request to its secretary.

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IEC/TR 60479-4

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# TECHNICAL REPORT

# RAPPORT TECHNIQUE

colour inside

## Effects of current on human beings and livestock – Part 4: Effects of lightning strokes

## Effets du courant sur le corps humain et sur les animaux domestiques – Partie 4: Effets de la foudre

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

# EFFECTS OF CURRENT ON HUMAN BEINGS AND LIVESTOCK –

## Part 4: Effects of lightning strokes

## FOREWORD

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IEC/TR 60479-4, which is a technical report, has been prepared by technical committee No.64: Electrical installations and protection against electric shock.

This second edition cancels and replaces the first edition, published in 2004 and constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

– the report has been completed with additional information on the influences and effects of natural electricity in the form of lightning strokes during thunderstorms;
– the definitions and technical terms have been updated;

– the explanation of the basic physical mechanisms for the dynamics of lightning where specified;
– the references to the relevant literature and the list of bibliography are updated;
– figures showing the current path during different interactions of lightning with the victim's body are updated.

The text of this technical report is based on the following documents:

| Enquiry draft | Report on voting |
|---|---|
| 64/1772/DTR | 64/1804/RVC |

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all the parts in the IEC 60479 series, under the general title *Effects of current on human beings and livestock*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

• reconfirmed,
• withdrawn,
• replaced by a revised edition, or
• amended.

**IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.**

# INTRODUCTION

IEC 60479-1, IEC 60479-2 and IEC 60479-3 deal with the effect of electric shock derived from electrical systems on the bodies of human beings and livestock. This part of IEC 60479, which is a technical report, describes the influence and effect of natural electricity in the form of lightning strokes during thunderstorms. Lightning current can consist of several uni-polar and/or bi-polar impulses with different peak values and durations; Clause 6 of IEC/TS 60479-2:2007[24][1] does not cover these effects.

The interaction of a lightning stroke with the victim's body is quite different from the usual experience with electric shock derived from electrical systems. The pathway often includes the head in lightning accidents. The importance of the cranial orifices as points of entry of lightning current has been noted, and from these the proximity of the pathway to the brainstem. The brain stem includes the respiratory centre, in contrast with pathways of shock current arising from electrical systems. In particular it should be pointed out that differences exist between accidents caused by a direct flash compared with those interactions which are caused by step voltages. Even very short single impulses of lightning can cause cardiopulmonary arrest [5], [6], [15] and [16].

The intense electric interactions with living organisms are very dangerous but, surprisingly in many cases, not always lethal. It is accepted that more than 90 % of lightning accidents involving humans are not fatal [1], [12]. Corresponding reliable data for livestock is not known. There is a large variation in outcome due to different environments, different activities of people and knowledge of first aid and quality of medical care [1], [5].

It has been necessary, therefore, to create a separate standard concerning the special effects of lightning strokes. The physical behaviour of lightning is shown as a basis. The interaction with a living body is then described, followed by the consequences for the life of the victim.

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1 References in square brackets refer to the bibliography.

# EFFECTS OF CURRENT ON HUMAN BEINGS AND LIVESTOCK –

# Part 4: Effects of lightning strokes

## 1 Scope and object

This part of IEC 60479, which is a technical report, summarizes the basic parameters for lightning and their variability insofar as they apply to human beings and livestock.

The possible direct and indirect interactions of strikes with bodies of living beings are indicated and the resulting effects caused by lightning currents for the organism are described.

The object of this report is to show the differences of effects on human beings and livestock due to lightning strokes versus those effects of electric shocks derived from electrical systems.

## 2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC/TS 60479-1:2005, *Effects of current on human beings and livestock – Part 1: General aspects*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC/TS 60479-1, in addition to the following definitions, apply.

### 3.1 Definitions of technical terms

**3.1.1**
**lightning flash**
atmospheric discharge consisting of one or more strokes

**3.1.2**
**lightning stroke**
single electrical discharge in a lightning flash

**3.1.3**
**lightning channel**
conducting path of the lightning current

**3.1.4**
**stepped and connecting leader**
stepped leader stepping down from a cloud and a connecting leader stepping up from points of field concentration beneath, noting that they are low current non-luminous processes leading to the return stroke when the two connect

**3.1.5**
**main stroke**
return stroke
bright lightened stroke with strong current discharge, which is initiated at that moment when the stepped and connecting leader comes into contact with the earth

**3.1.6**
**downward flash**
lightning flash initiated by a downward leader from a cloud to earth

**3.1.7**
**upward flash**
lightning flash initiated by an upward leader from earth to cloud; that part of a stroke when the leader grows from earth to cloud

**3.1.8**
**continuing current**
mean current of the long-lasting component of the lightning current

**3.1.9**
**peak value of current**
maximum value of the lightning current

NOTE Values are given in Table A.2 and Figure A.5 of IEC 62305-1:2010 [7].

**3.1.10**
**flash charge**
time integral of the lightning current for the entire lightning duration

NOTE This value ranges from 0,2 °C to 350 °C for the majority of positive and negative lightning strokes [7].

**3.1.11**
**impulse charge**
short stroke charge
time integral of the lightning current for the impulse part of the lightning duration

NOTE This value ranges from 0,22 °C to 150 °C for the majority of positive and negative lightning strokes [7].

**3.1.12**
**specific energy**
energy dissipated by the lightning current in a unit resistance

NOTE It is the integral of the square of the lightning current for the duration of the lightning. This value ranges from $6 \times 10^3$ J/Ω to $1,5 \times 10^7$ J/Ω for the majority of positive and negative lightning strokes [7].

**3.1.13**
**average steepness of current wave front**
average rate of change of current calculated over 10 % to 90 % of peak amplitude of the wave front [7]

NOTE This value ranges from 0,2 kA/μs to 99 kA/μs for the majority of positive and negative lightning strokes.

**3.1.14**
**stroke duration**
Time from the initiation of an atmospheric discharge until the time that particular stroke has been extinguished (the range of 3.1.5) and is 15 μs to 2000 μs for the majority of positive and negative lightning strokes [7]

**3.1.15**
**stroke interval**
time interval between the beginnings of successive strokes

**3.1.16**
**total flash duration**
Time from the beginning the first stroke to the end of the last stroke with a time range of 0,1 ms to 1100 ms for the majority of positive and negative lightning flashes [7]

NOTE 1 Experience shows that the statistical distribution of the parameters of total flash duration as expressed by Definition 3.1.16, can be assumed to have a logarithmic normal distribution.

NOTE 2 A flash is made up of a number of strokes. A continuing current may result and continue for some time. The duration of the flash is therefore dependent on the stroke duration, the number of strokes of the flash and the duration of any continuing current. All of these are variable and statistically described.

## 3.2 Definitions of interactions

**3.2.1**
**direct stroke**
interaction whereby the tip of the stepped and connecting leader attaches directly to the living being (see Figure 2)

**3.2.2**
**contact voltage**
potential difference between accessible points when touched simultaneously by a living being (see Figure 3)

NOTE In some texts this has been erroneously referred to as “contact potential” or “touch voltage”

**3.2.3**
**side flash**
electric arc between two objects, at least one of which is contacted by lightning (see Figures 4 and 7) )

**3.2.4**
**step voltage**
voltage on the earth’s surface between two points

[IEC 60050-195:1998, 195-05-12, modified] [25]

NOTE The possible resulting currents are shown in Figures 5 and 7. .

**3.2.5**
**streamer current**
current flowing through an individual as that individual serves as the starting point for an upward streamer which ultimately does not join a stepped leader to form a conducting channel (see Figure 8)

**3.2.6**
**flashover**
electric arc over the surface of the body carrying a significant proportion of the current

NOTE It may occur with the other combinations above (see Figure 2).

## 3.3 Definitions of effects on organisms

**3.3.1**
**physiological effects**
reaction due to external electrical stimulation of excitable cells, such as all kinds of skeletal muscle, smooth muscle of arteries and veins, cardiac muscle, nerves and all the structures of the brain

NOTE These effects are transient and stimulate the tissue within the limits of physiological function.

**3.3.2**
**pathophysiological effects**
stimulatory or inhibitory effects which lead to reversible or irreversible dysfunction of the affected structures of the organism

NOTE 1 These effects are of long duration and are produced by stimuli outside usual physiological magnitudes

NOTE 2 This group of effects includes keraunoparalysis which is a transient paralysis of the muscular structures in the line of the current. Its cause is uncertain.

**3.3.3**
**thermal effect**
pathophysiological effect of electrical current which results from local and transient heating of the affected structures up to temperatures where parts of cells and organelles become denatured

NOTE The effect of evaporation remains to be proved [17].

## 4 Physics of lightning

The explanation of the basic physical mechanisms for the onset and the dynamics of lightning is very complicated. Recent explanation takes into account that a tripolar layered cloud is generated by microscopic charge transfer between soft hail particles (also called graupel) and ice crystals [3].

Lightning is a transient, high-current discharge whose path length is measured in kilometres. Well over half of all flashes occur wholly within the cloud and are called intra-cloud (IC) discharges. Cloud-to-ground (CG) lightning has been studied more extensively than other forms of lightning because of its practical importance (for instance, as a cause for injuries and death, disturbances in power and communication systems and the ignition of forest fires) and because lightning below a cloud is more easily studied with optical techniques. Cloud-to-cloud and cloud-to-air discharges occur less frequently than either IC or CG lightning. All discharges other than CG are often combined under the general term "cloud discharges".

Four different types of discharges between cloud and earth have been identified (Figure 1). Negative CG flashes probably account for about 90 % of the CG discharges world-wide (Figure 1a), and less than 10 % of lightning discharges are initiated by a downward-moving positive leader (Figure 1c) [4]. Ground-to-cloud discharges are initiated by leaders that move upward from the earth (Figurse 1b et 1d). These upward-initiated flashes are relatively rare and usually occur from mountain peaks and tall man-made structures [3].

Other important physical parameters are the specific energy per stroke, the average steepness of current rise within a stroke, as well as the stroke duration and total flash duration where there is more than one stroke in a flash.

The mechanical effects are related to the peak value of the current and specific energy. The thermal effects are related to the specific energy when resistive coupling is involved and to the total charge or impulse charge when arcs develop. The highest peak values, specific energy and impulse energy occur in positive lightning strokes.

The inductive coupling is related to the steepness of the lightning current front. The highest value of this parameter occurs in subsequent negative strokes [5].

Thunder accompanies lightning and is generated by super-heated air at the channel, which causes air pressure waves.

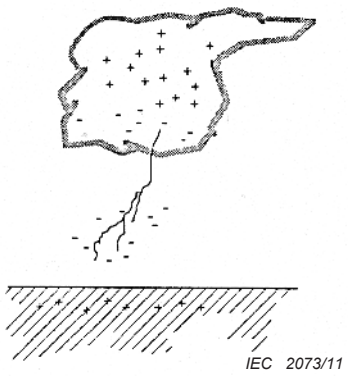



**Figure 1a – Lightning begins with a negative charged leader moving downwards**

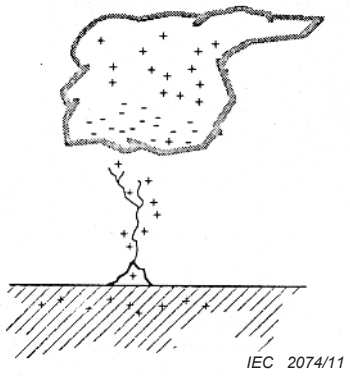



**Figure 1b – Lightning has a positively charged leader, and hence this type effectively lowers negative charge to earth**

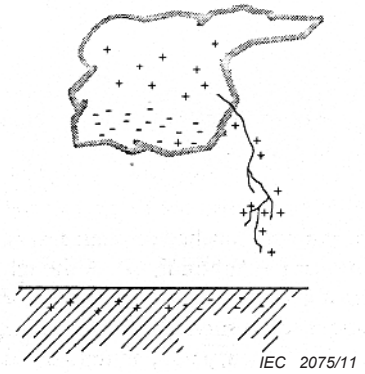



**Figure 1c – Discharges are initiated by a downward moving positive leader**

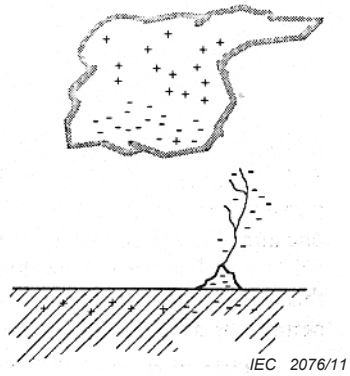



**Figure 1d – The leader is charged negatively and effectively lowers positive charge (reprinted from [4])**

**Figure 1 – Categorization of lightning [4]**

## 5 Interaction of strokes with human beings and livestock

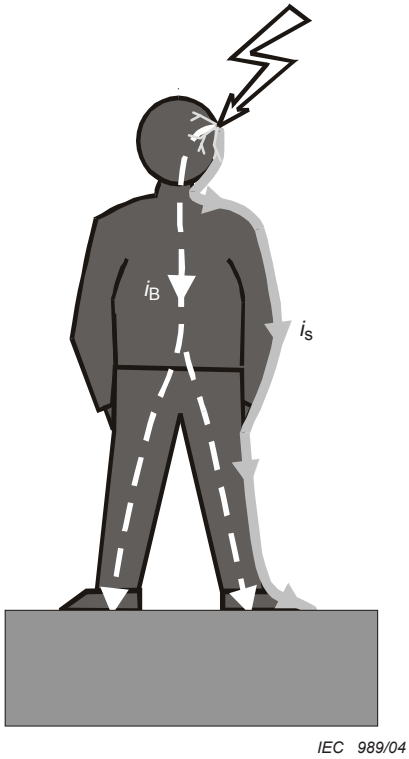
### 5.1 General

The possible interaction of lightning with human beings and livestock depends on the resulting time course and pathway of the current in the body and on its surface. As the temporal and spatial current distribution of strokes varies, so the effects on living organisms are different. The effects of magnetic fields derived from the lighting stroke upon a living organism are not thought to be significant [23].

### 5.2 Description of direct strike

When the tip of the downward stepped leader has reached a height of some tens of metres above ground level, the resulting field strength attains a critical value so that a short upward streamer can be initiated from a conductive object or victim. The flow of current of the whole discharge goes direct via the victim's body (Figure 2).

A description of direct lightning stroke interaction is given in 5.6.




**Key**

$i_B$ body current

$i_S$ surface flashover current

**Figure 2 – Direct stroke**

### 5.3 Description of contact voltage

When an object, not necessarily metallic, is struck by lightning, points on its surface are raised in potential. When a person contacts one of these points and another, possibly earth, to complete a circuit, partial lightning current will flow through that person. This contact voltage is determined by a resistive and an inductive component [5] (Figure 3).

$$u = i_L R + L\mathrm{d}i_L/\mathrm{d}t$$

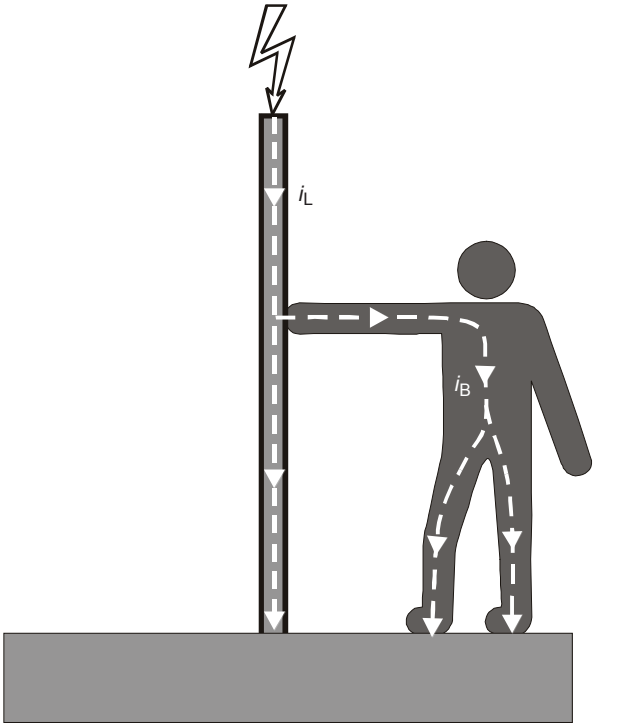
where

$u$ is the resulting contact voltage;

$i_L$ is the current through a vertical structure;

$R$ is the resistance between the points of contact;

$L$ is the inductance between the points of contact.




**Key**

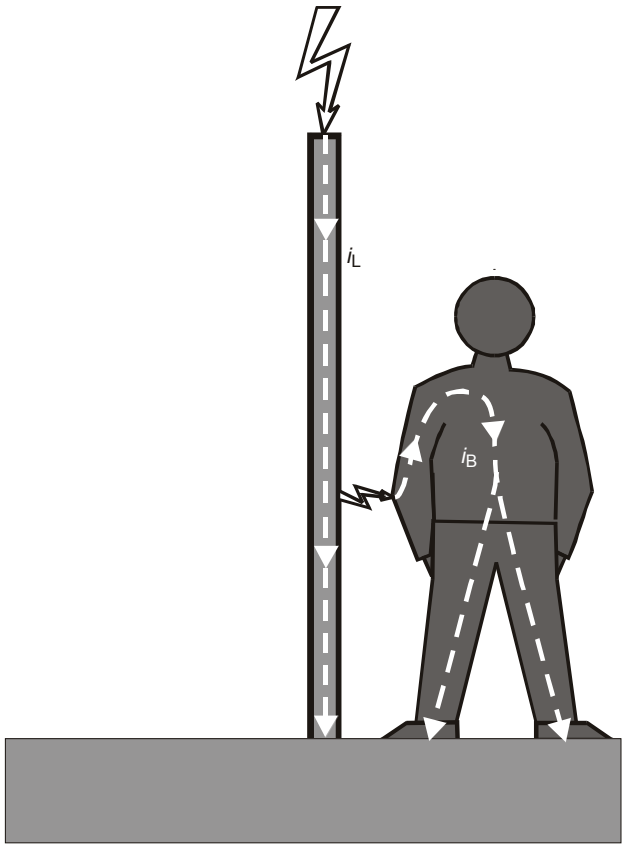
$i_L$ lightning current

$i_B$ body current

**Figure 3 – Contact voltage**

### 5.4 Description of side flash

When a vertical structure conducts lightning current and a person is near, but not touching it, the potential builds up on the object in the same way as with contact voltage. The resulting potential difference may exceed the electrical breakdown strength of the gap between the object and a person standing nearby. Then a side flash occurs (Figure 4)




**Key**

$i_L$ lightning current

$i_B$ body current

**Figure 4 – Side flash**

### 5.5 Description of step-voltage

Lightning current through the ground can lead to a step voltage (Figure 5). The pathway of the currents in quadrupeds includes the heart (Figure 6). Another reason that quadrupeds are much more likely to be killed is that they often stand in muddy ground so that their legs are in particularly good contact with the ground. Even in two-legged human beings, current can flow through the heart (Figure 7) [5]. Usually, if the pathway of step voltages for humans does not include the heart, the victim is often temporarily paralysed from the waist down (keraunoparalysis).

The current distribution can be extremely irregular depending on the non-uniformity of the resistance distribution in the ground.

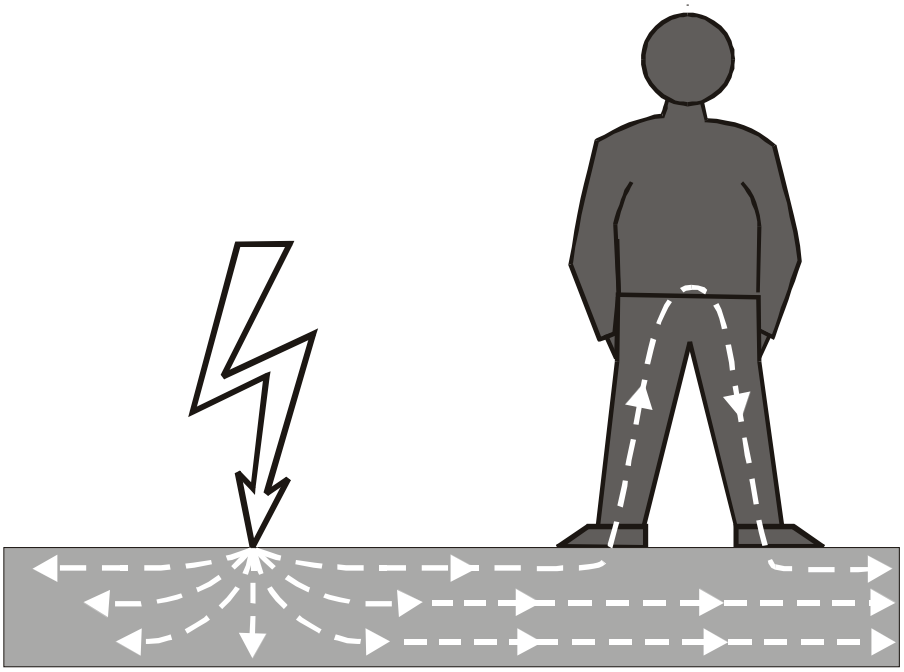



**Figure 5 – Step voltage**

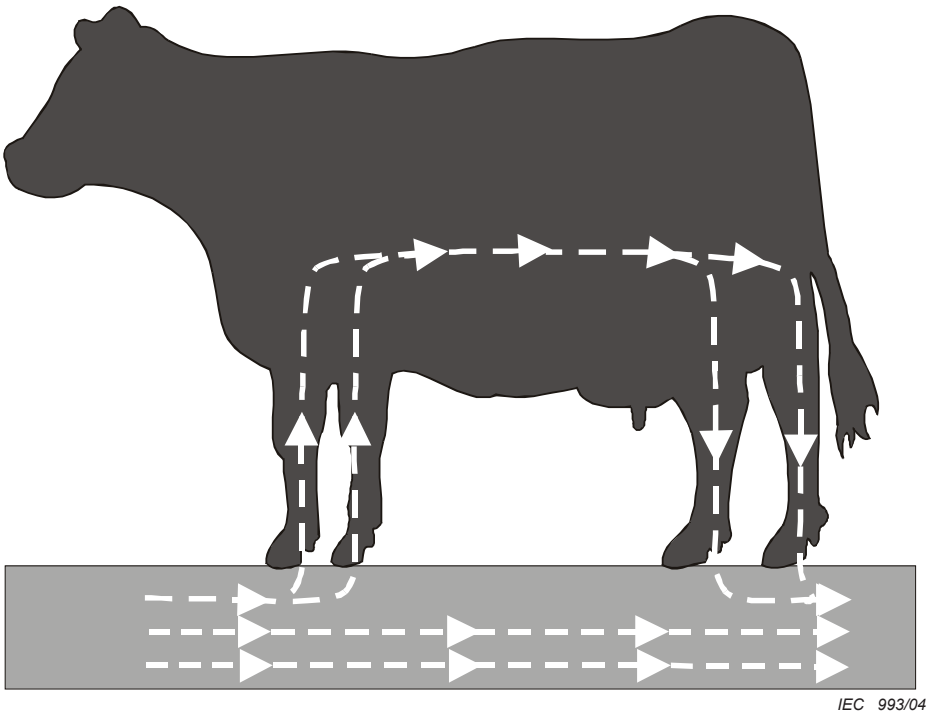



**Figure 6 – Step voltage on quadrupeds**

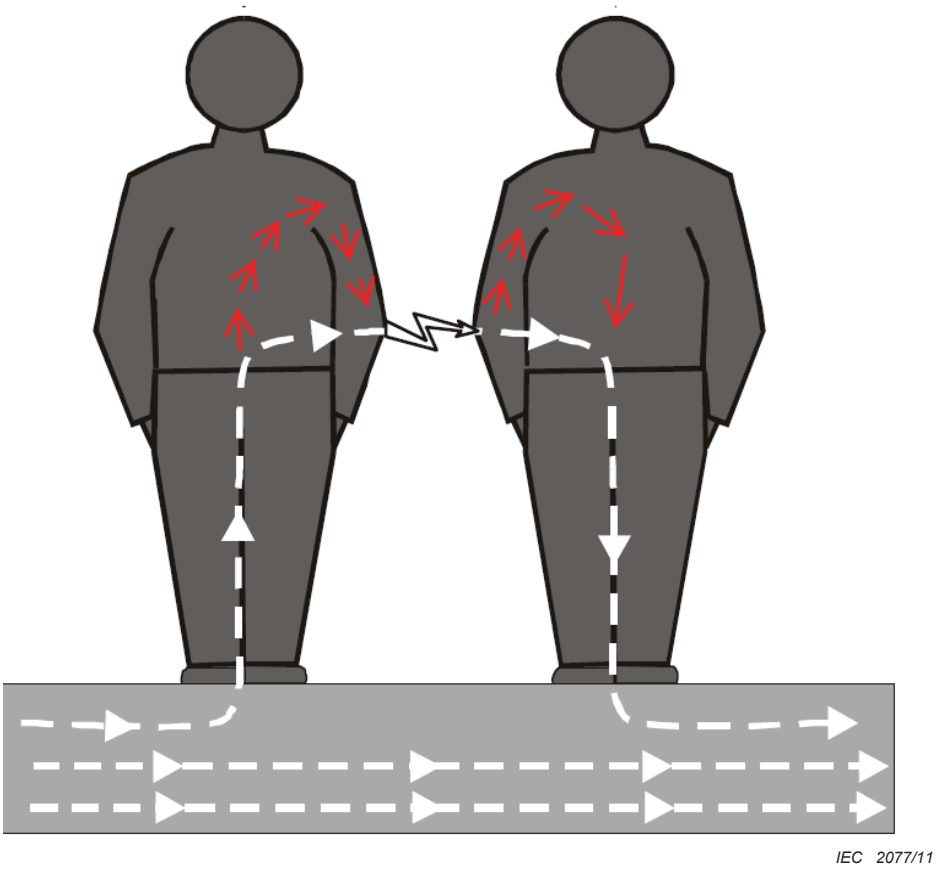



**Figure 7 – Step voltage with side flash**

### 5.6 Description of streamer shock

When a victim is within the field of the downward stepped leader, a short, upgoing leader may be generated from them which, however, does not ultimately join the stepped leader to form a conducting channel. The current required flows through a victim for a short period and is capable of producing injury (Figure 8).

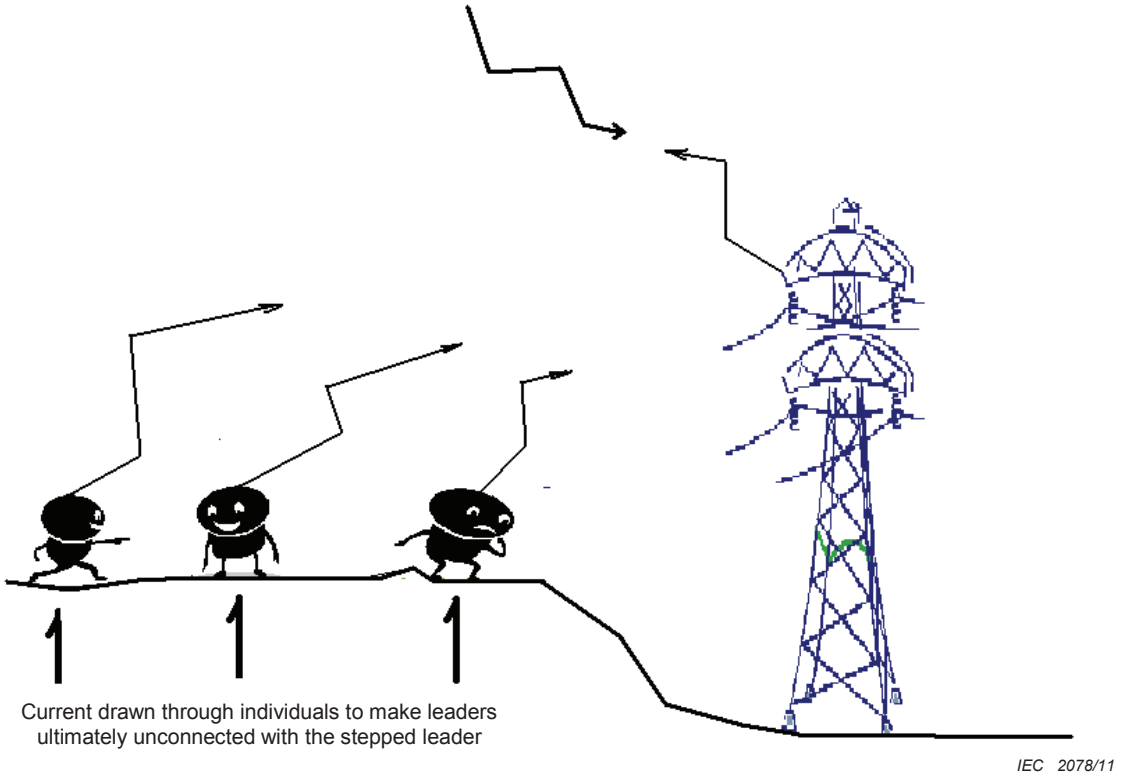



**Figure 8 – Upward streamer current**

### 5.7 Description of flashover

Flashover occurs quickly after two processes develop. A small leader current flows for about 50 μs, then a large current due to return stroke attachment, occurs for about 0,5 μs. External flashover then occurs, resulting in reduction of voltage and internal current flow. The flashover, as a path of the lightning current along the surface of the body, acts as a current by-pass for the internal parts of the body. A plasma field between the contact points (10-20 V/cm) lasts for about 0,1 s. The potential difference across the body contact points is high enough for an electric breakdown to continue in the air. After the breakdown, the current through the body is reduced to only a few amperes (Figure 1).

## 6 Effects of lightning strokes on the body of human beings and livestock

### 6.1 General

If electric current flows through the body of living beings, damage or malfunction can occur. Direct strike obviously gives rise to the greatest harm while the earth potential rise mechanism is the least injurious. Injury due to contact voltage and side flash are intermediate to these and can cause injury similar to that of direct strike.

### 6.2 Physiological effects

External electrical stimulation by lightning induces activity in all kinds of neuromuscular structures, including spasm in the vascular field, cardiac arrest, predominately in asystole or, rarely, fibrillation.

Cardiac conduction activity may also be disrupted, resulting in lack of coordinated heart pumping, which is the heart's essential function. Resulting loss of blood flow is fatal [19].

Respiratory arrest also occurs and lasts much longer than cardiac arrest. While the heart may restart, a secondary cardiac arrest due to lack of oxygen will occur, and the pump action is lost again, unless ventilation is given.

Involuntary skeletal muscle reactions may happen, which can lead to strong contractions and seizures, which can result in secondary effects.

### 6.3 Pathophysiological effects

These effects include damage of a non-thermal nature to excitable and non-excitable cells. Membrane rupture is possible, even perforation. Recovery may not take place immediately or may never occur. Secondary effects may have serious consequences. Table 1 summarizes specific features of lightning injury progression, and consequences for body physiology.

### 6.4 Thermal effects

Table 1 also summarizes the range of injuries seen from lightning stroke and shows changes of pathophysiology. Thermal effects of lightning current, for example burns, are not marked and this is thought to be due to the very short duration of lightning impulses.

### 6.5 Comparison between effects of electric shock derived from electrical systems and lightning

It has been emphasized that injury from lightning stroke is markedly different from that due to either low voltage or high voltage electricity derived from electrical systems, whether domestic or industrial. Table 2 summarizes these differences. There is, however, no basis to the dogma that recovery after ‘longer than normal’ cardiac arrest can occur. Details of the specific nature of lightning injuries are covered in [11], [13], [15], [16] and [19]

### 6.6 Percentage occurrence

Present knowledge suggests that the various mechanisms of lightning shock occur as follows:

– direct strike 3 % – 5 %;
– side flash 20 % – 25 %;
– contact potential 15 % – 20 %;
– step voltage 40 % – 50 %;
– upward streamer 10 % – 15 %.

Present knowledge suggests the mortality rate is approximately 10 %.

**Table 1 – Causes of lightning death and most typical reported consequent disorders [11-16], [20]**

| | |
|---|---|
| **LIGHTNING DEATH** | Mostly asystole, some ventricular fibrillation<br>Cardiorespiratory progression (see 6.1)<br>Secondary multisystem failure |
| **CARDIOPULMONARY INJURY** | Arrhythmiae<br>Sympathetic, and cardiac induced, arterial pressure changes<br>Electrocardiographic changes, usually transient<br>Cardiac failure<br>Pulmonary contusion and oedema |
| **IMMEDIATE NEUROLOGICAL EFFECTS** | Loss of consciousness<br>Brain stem dysfunction<br>Cerebellar and basal ganglion haemorrhage<br>Peripheral neurovascular spasm. Keraunoparalysis<br>Intracerabral haemorrhage<br>Seizures |
| **LONG TERM NEUROLOGICAL EFFECTS** | Paraesthesiae<br>Pain syndromes<br>Neuropathy<br>Parkinsonism<br>Spinal cord change |
| **IMMEDIATE PSYCHIATRIC EFFECTS** | Confusion<br>Amnesia<br>Anxiety<br>Aphasia, and hysterical changes |
| **LONG TERM PSYCHIATRIC EFFECTS** | Depression, possibly organic<br>Anxiety states<br>Phobias<br>Psychotic Illness, both production and alteration of existing disease<br>Memory disorder<br>Sleep disorder<br>Loss of cognitive ability<br>Aesthenia and fatigue<br>Post traumatic stress disorder |
| **BURNS AND CUTANEOUS MARKINGS** | Entry and exit burns (often deep and closely circumscribed)<br>Flash<br>Linear burn<br>Arborescent burn (Lichtenberg figure, ferning)<br>Punctate flower like burn (possibly a variant of the Arborescent burn)<br>Contact burn |
| **CONTUSIVE BLAST INJURY** | Exploded, torn and shredded clothing<br>Body contusion (skin, brain, lung, bowel, etc.) |
| **TRAUMA** | Blow bruise laceration<br>Fractures<br>These may be primary to the strike, or secondary due to induced motion |
| **SPECIAL SENSES** | Tympanic membrane rupture<br>Deafness<br>Tinnitus and vertigo<br>Blindness<br>Retinitis<br>Retinal detachment and macular and retinal punctation<br>Cataract<br>Uveal Inflammation |

**Table 2 – Differences between low voltage and high voltage injuries from electrical systems, and lightning injuries [1], [11-16], [20]**

| Item | Low voltage | High voltage | Lightning |
|---|---|---|---|
| **Voltage** | <1 000 V a.c. or <1 500 V d.c. | >1 000 V a.c. or >1 500 V d.c. | Complex and impulsive, with or without flashover |
| **Location** | Domestic and industrial, including workplace<br>Rural<br>Children represented | Industrial – mostly electrical workers | Outdoors, more often during recreation<br>Indoors, telephone or other line mediated |
| **Common mechanisms** | Interference with appliances and other electrical equipment<br>Faulty appliances<br>Amateur wiring, especially extension leads<br>Ladder contact with live parts | Installation service and repair<br>Inadequate safety practice or procedures<br>Misuse of equipment | Direct strike<br>Side flash or contact potential<br>Step voltage<br>Streamer initiation |
| **Type of current** | 50/60 Hz a.c. | 50/60 Hz a.c. | Impulse discharge, often multiple, and possible continuing component |
| **Source** | Domestic and workplace outlets wiring and appliances | Reticulation, installations, supply and control mechanisms | Natural atmospheric discharge |
| **Duration of Contact** | Maybe prolonged if let-go exceeded | Short or long, short being more likely if thrown | Impulsive and ultrashort, though continuing current may occur |
| **Mode of death** | Ventricular fibrillation (VF) | VF more likely than asystole | Asystole much more likely than VF (also respiratory paralysis) |
| **Burns** | Often severe, deep, and extensive necessitating amputation and/or fasciotomy | May be similarly severe | Minor |
| **Lichtenberg figures** | Absent | Can be present | Common |
| **Electro-poration** | Demonstrated | Demonstrated | Yet to be determined |
| **Muscle damage** | Common | May be present | Rare |
| **Renal consequences** | Myoglobinuria common | Myoglobinuria known | Rare |
| **Direct traumatic tissue damage (by current)** | Common | Common | Known but rare |
| **Secondary traumatic tissue damage (by being thrown)** | Common | Common | Known but rare |
| **Prevention** | Protective devices and design<br>Personal practice | Protective devices and design<br>Safety codes | Codes of personal behaviour<br>Structure protection<br>Crowd Protection |
| **First aid** | Avoid injury to rescuer separating victim from source<br>Alternatively switch current off<br>CPR (cardio pulmonary resuscitation) as per known protocol obtain medical help | Avoid injury to rescuer separating victim from source<br>Alternatively switch current off<br>CPR (cardio pulmonary resuscitation) as per known protocol. Obtain medical help | Immediate CPR (cardio pulmonary resuscitation)<br>Summon medical help |

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