Fundamental physical principles and definitions

Explosion

An explosion is the sudden chemical reaction of a combustible substance with oxygen, involving the release of high energy. Combustible substances can be gases, vapors, fumes or dust. An explosion can only take place if the following three factors coincide:

1. Combustible substance (in the relevant distribution and concentration)

2. Oxygen (in the air)

3. Source of ignition (e.g. electrical spark)

Primary and secondary explosion protection

Integrated explosion protection

1. Prevention of dangerous potentially explosive atmospheres

2. Prevention of the ignition of dangerous potentially explosive atmospheres

3. Limiting the explosion to a negligible degree

The principle of integrated explosion protection requires all explosion protection measures to be carried out in a defined order. A distinction is made here between primary and secondary protective measures.

Primary explosion protection covers all measures that prevent the formation of a potentially explosive atmosphere.

What are the protective measures that can be taken to minimize the risk of an explosion?

- Avoidance of combustible substances
- Inerting (addition of nitrogen, carbon dioxide, etc.)
- Limiting of the concentration
- Improved ventilation

Secondary explosion protection is required if the explosion hazard cannot be removed or can only be partially removed using primary explosion protection measures.

When considering safety-related factors, it is necessary to know certain characteristic quantities of combustible materials.

Flash point

The flash point for flammable liquids specifies the lowest temperature at which a vapor-air mixture forms over the surface of the liquid that can be ignited by a separate source.

If the flash point of such a flammable liquid is significantly above the maximum occurring temperatures, a potentially explosive atmosphere cannot form there. However, the flash point of a mixture of different liquids can also be lower than the flash point of the individual components.

In technical regulations, flammable liquids are divided into four hazard classes:

Hazard class	Flash point
AI	<21 °C
AII	21 ... 55 °C
AIII	>55 ... 100 °C
B	<21 °C, at 15 °C soluble in water

Explosion limits

Combustible substances form a potentially explosive atmosphere when they are present within a certain range of concentration (see "Area subject to explosion hazard").

If the concentration is too low (lean mixture) and if the concentration is too high (rich mixture) an explosion does not take place. Instead slow burning takes place, or no burning at all. Only in the area between the upper and the lower explosion limits does the mixture react explosively if ignited. The explosion limits depend on the surrounding pressure and the proportion of oxygen in the air (see the table below).

We refer to a deflagration, explosion, or detonation, depending on the speed of combustion. A potentially explosive atmosphere is present if ignition represents a hazard for personnel or materials. A potentially explosive atmosphere, even one of low volume, can result in hazardous explosions in an enclosed space.

Area subject to explosion hazard

100 % vol	Air concentration	0 % vol
Mixture too weak No combustion	Area subject to explosion hazard	Mixture too rich Partial combustion, no explosion
← Lower explosion limit upper →		
0 % vol		100 % vol
Concentration of combustible substance		

Dusts

In industrial environments, e.g. in chemical plants or in flour mills, solid matter is often present in small particles and also in the form of dust.

The term "dust" is defined in DIN EN 50281-1-2 as small solid particles in the atmosphere that are deposited due to their own weight but which remain in the atmosphere for some time in the form of a dust/air mixture". Dust deposits are comparable to a porous body and have an air component of up to 90 %. If the temperature of dust deposits is increased, this can result in self-ignition of the combustible substance in the form of dust.

When deposits of dust with a small particle size are disturbed, there is a risk of explosion. This risk increases as the particle size decreases, because the surface area of the hollow space increases. Dust explosions are often the result of disturbed glowing dust deposits that carry the initial spark within them.

Explosions of gas/air or vapor/air mixtures can also disturb dust, in which case the gas explosion can become a dust explosion.

In coal mines, methane gas explosions often caused coal dust explosions which surpassed the gas explosions in their effects.

The risk of an explosion is prevented by using explosion-proof equipment in accordance with its protection capability. The identification of the equipment categories mirrors the effectiveness of the explosion protection and therefore its use in the corresponding areas subject to explosion hazard.

The potential risk of explosive dust atmospheres and the selection of appropriate protective measures are assessed on the basis of safety characteristics for the materials involved. Dusts are subdivided here in accordance with two of their material-specific characteristics:

- Conductivity
  Dusts that have a specific electrical resistance of up to 10^3 Ωm are classed as conductive.
- Combustibility
  Combustible dusts, however, are characterized by the fact that they can burn or glow in air and that they can form explosive mixtures at atmospheric pressure and at temperature from –20 to +60 °C in combination with air.

Examples of safety characteristics in the case of disturbed dust include the minimum ignition energy and the ignition temperature, whereas in the case of dust deposits, the glowing temperature is a characteristic feature.

Minimum ignition energy

The application of a certain amount of energy is required to ignite a potentially explosive atmosphere.

The minimum energy is taken to be the lowest possible converted energy, for example, the discharge of a capacitor, that will ignite the relevant flammable mixture.

The minimum energy lies between approximately 10^{-5} J for hydrogen, and several Joules for certain dusts.

What can cause ignition?

- Hot surfaces
- Adiabatic compression
- Ultrasound
- Ionized radiation
- Open flames
- Chemical reaction
- Optical radiation
- Electromagnetic radiation
- Electrostatic discharge
- Sparks caused mechanically by friction or impact
- Electrical sparks and arcing
- Ionized radiation

Legislative basis and standards

Legislative basis of explosion protection

Globally, explosion protection is regulated by the legislatures of the individual countries. At the international level, the IEC is attempting to get closer to the aim of "a single global test and certificate" by introducing the IECEx Scheme.

EU directives

In the European Union, explosion protection is regulated by directives and laws.

Electrical equipment for use in potentially explosive atmospheres must therefore possess test certification or approval. The relevant systems and equipment are graded as systems requiring monitoring and must only use devices approved for this purpose. In addition, commissioning, modification, and regular safety inspections must only be accepted or carried out by approved institutions or societies. The EU directives are binding for all member states and form the legal framework.

Selection of important EU directives

Short designation	Full text	Directive no.	Valid as of:	End of transition period
EX Directive (ATEX 95)	Directive of the European Parliament and Council of March 23, 1994 on the harmonization of laws of the Member States concerning equipment and protective systems intended for use in potentially explosive atmospheres	94/9/EG	03/01/96	06/30/03
ATEX 137	Minimum regulations for improving the health protection and safety of employees that could be endangered by potentially explosive atmospheres	1999/92/EG	12/16/99	06/30/03

National laws and regulations

In general, the EU directives are European laws that must be incorporated by the individual member states unmodified by ratification. Directive 94/9/EU was adopted completely into the German explosion protection regulation ExVO. The underlying legislation for technical equipment is the Equipment Safety Law (GSG) to which ExVO is appended as a separate regulation (11th GSGV).

In contrast, ATEX 137 (Directive - 1999/92/EC) contains only “Minimum regulations for improving the health protection and safety of employees that could be endangered by potentially explosive atmospheres”, so that each EU member state can pass its own regulations beyond the minimum requirements. In the German Federal Republic, the contents of the directive have been implemented in factory safety legislation. In order to simplify the legislation, the contents of several earlier regulations have been simultaneously integrated into the factory safety legislation ('BetrSichVO'). From the area of explosion protection, these are:

- The regulation concerning electrical installations in potentially explosive atmospheres (ElexV)
- The acetylene regulation
- The regulation concerning flammable liquids

These regulations became defunct when the factory safety legislation came into force on 01/01/2003.

Explosion protection guidelines (EX-RL) of the professional associations

In the “Guidelines for the prevention of hazards from potentially explosive atmospheres with listed examples” of the *German Chemicals Professional Association*, specific information is given on the hazards of potentially explosive atmospheres and measures for their prevention or limitation are listed. Of special use are the examples of individual potentially explosive process plants in the most diverse industrial sectors in which these measures are listed in detail. Valuable suggestions and risk evaluations are available for planners and operators of such plants or similar process plants. While the EX Directives have no legal status, they are nevertheless to be regarded as important recommendations that can also be called upon for support in deciding legal questions in the event of damage.

Standards

There are a host of technical standards worldwide for the area of explosion protection. The standards environment is subject to constant modification. This is the result of both adaptation to technical progress and increased safety demands in society. International efforts towards harmonization also contribute to the aim of achieving the most uniform global standards possible and the resulting removal of barriers to trade.

EU standards

The standards for explosion protection valid in the European Union are created on the basis of the EU Directives under the leadership of CENELEC (European Committee for Electrotechnical Standardization). CENELEC comprises the national committees of the member states. Since, in the meantime, standardization at international level gained greatly in importance through the dynamism of the IEC (International Electrotechnical Commission), CENELEC has decided only to pass standards in parallel with the IEC. In practice, this means European standards in the area of electrical/electronic systems will now be created or redefined almost exclusively on the basis of IEC standards as harmonized EN standards. For the area of explosion protection, these are mainly the standards of the EN 60079 series. The numbers of harmonized European standards are built up according to the following system:

IEC/EN	60079-0	:	1997	**Meaning**
				Year of issue
				Number of standard
				Harmonized European Standard

IEC

At the international level, the IEC (International Electrotechnical Commission) issues standards for explosion protection. The Technical Committee TC31 is responsible. Standards for explosion protection are found in the IEC 60079-x series (previously IEC 79-x). The x represents the numbers of the individual technical standards, e.g. IEC 60079-7 for intrinsic safety.

Classification of explosion-protected equipment

Identification

The identification of electrical equipment for areas protected against explosion hazards should include:

- The manufacturer who supplied the equipment
- A designation that identifies it
- The implementation range
  - In underground mines I
  - Other areas II
  - Gases and vapors – G -, dusts – D – or mines – M -,
- The categories that specify whether the device can be used for specific zones
- The type(s) of protection to which the equipment complies
- The testing authority that issued the test certificate, the standard or version of the standard to which the equipment complies – including the registration number of the certificate from the testing authority, and if necessary, the special conditions to be observed.
- The data that is normally required for an identical item of equipment in industrial design should also be provided.

Example for identification according to 94/9/EU

CE	0158	Ex II 2D	IP65	T125 °C	**Meaning**
					Temperature range
					Enclosure protection class
					Ex protection zone
					Nominated authority for certification of the QA system in accordance with 94/9/EU
					Conformity mark

Equipment identification code	Meaning
SAMPLE_COMPANY Type 07-5103-.../...	Manufacturer and type designation
Ex II 2D IP65 T 125 °C	Acc. to EN 50281-.-. Protection afforded by housing, IP65 protection class Max. surface temperature +125 °C
PTB 00 ATEX 1081	Serial No. of test authority
	ATEX generation
	Certified 2000
	Symbol of test authority

Device groups/categories

Devices are classified into device groups:

- Device group I
  - in underground operations
  - in mines
  - as well as open-cast operations
- Device group II
  - Devices for use in the other areas

Each device group contains equipment that is in turn assigned to different categories (Directive 94/9/EC).

The category specifies the zone in which the equipment may be used.

Comparison of device groups and categories

Device group I (mining)		
Category	M1: Extremely high level of safety	M2: High level of safety
Sufficient safety	Through 2 protective measures/in the event of 2 faults	Must be switched off in the presence of an Ex atmosphere.

Device group II (other areas subject to explosion hazard)						
Category	1: Extremely high level of safety		2: High level of safety		3: Normal level of safety	
Sufficient safety	Through 2 protective measures/in the event of 2 faults		In the event of frequent device faults/in the event of one fault		In the case of fault-free operation	
Use	Zone 0	Zone 20	Zone 1	Zone 21	Zone 2	Zone 22
Atmosphere	G (gas)	D (dust)	G	D	G	D

Zones

Potentially explosive atmospheres are divided into zones. Division into zones depends on the chronological and geographical probability of the presence of a hazardous, potentially explosive atmosphere.

Information and specifications for zone subdivision can be found in EN/IEC 60079-10.

Equipment in areas where a constant explosion hazard exists (Zone 0/20) are subject to stricter requirements, and by contrast, equipment in less hazardous areas (Zone 1/21, Zone 2/22) is subject to less stringent requirements. In general, 95 % of systems are installed in Zone 1 and only 5 % of equipment is in Zone 0.

Subdivision of combustible dusts into different zones

Flammable gases, vapors, and mist		
Zone	Equipment category	Description
0	1G	Hazardous, potentially explosive atmosphere present **continuously** and **over extended periods**.
1	2G 1G	It is to be expected that a hazardous, potentially explosive atmosphere will only occur **occasionally**.
2	3G 2G 1G	It is to be expected that a hazardous, potentially explosive atmosphere will occur **only rarely** and then only **for a short period**.

Flammable dusts		
Zone	Equipment category	Description
20	1D	Areas where a potentially explosive atmosphere comprising dust-air mixtures is present **continuously, over extended periods** or **frequently**.
21	2D 1D	Areas where it is expected that a hazardous, potentially explosive atmosphere comprising dust-air mixtures will occur **occasionally** and **for short periods**.
22	3D 2D 1D	Areas in which it is not to be expected that a potentially explosive atmosphere will be caused by stirred-up dust. If this does occur, then in all probability only **rarely** and **for a short period**.

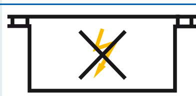
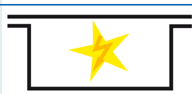
Types of protection

The protection types are design measures and electrical measures carried out on the equipment to achieve explosion protection in the areas subject to explosion hazard.

Protection types are secondary explosion protection measures. The scope of the secondary explosion protection measures depends on the probability of the occurrence of a hazardous, potentially explosive atmosphere.

Electrical equipment for areas subject to explosion hazard must comply with the general requirements of IEC/EN 60079-0 and the specific requirements for the relevant type of protection in which the equipment is listed.

The types of protection listed on the pages below are significant in accordance with IEC/EN 60079-0. All types of protection are based on different principles.

Types of protection for gases						Use in Zone		
Degree of protection	Coding	Schematic diagram	Basic principle	Standard	Examples	0	1	2
General requirements			General requirements for the type and testing of electrical equipment intended for the Ex area	IEC/EN 60079-0				
Increased safety	e		Applies only to equipment, or its component parts, that normally does not create sparks or arcs, does not attain hazardous temperatures, and whose mains voltage does not exceed 1 kV	IEC/EN 60079-7	Squirrel-cage motors, terminals, connection boxes		•	•
Flameproof enclosure	d		If an explosion occurs inside the enclosure, the housing will withstand the pressure and the explosion will not be propagated outside the enclosure	IEC/EN 60079-1	Squirrel-cage motors, switchgear, transformers		•	•
Types of protection	n	Zone 2 Several protection types are included under this type	Slightly simplified application of the other Zone 2 protection types – "n" stands for "non-igniting"	EN 50021 [1] IEC/EN 60079-15	Squirrel-cage motors, programmable controllers			•

1) From 2007 IEC/EN 60079-15

Types of protection for dusts					Use in Zone		
Type of protection	Coding	Basic principle	Standard	Examples	20	21	22
Pressurized enclosure	pD	Penetration of a surrounding atmosphere into the housing of electrical equipment is prevented by retaining an ignition protection gas (air, inert gas or other suitable gas) internally at a higher pressure than the surrounding atmosphere.	EN 50281 IEC 61241	Equipment in which sparks, arcs or hot components occur during operation	•	•	•
Encapsulation	mD	Components that can ignite a potentially explosive atmosphere through sparks or heating are embedded in a potting compound such that the explosive atmosphere cannot ignite. This is achieved by completely covering the components with a potting compound that is resistant to physical (particularly electrical, thermal and mechanical) as well as chemical influences.	EN 50281 IEC 61241	Switchgear and control cabinets	•	•	•
Protection by housing	tD	The housing is so thick that ingress of combustible dust is not possible. The external surface temperature of the housing is limited.	EN 50281 IEC 61241	Measuring and monitoring equipment	•	•	•
Intrinsic safety	iaD, ibD	Current and voltage are limited so that intrinsic safety is guaranteed. Sparks or thermal effects cannot ignite a dust/air mixture.	EN 50281 IEC 61241	Sensors and actuators	•	•	•

Temperature classes

The ignition temperature of flammable gases or a flammable liquid is the lowest temperature of a heated surface at which the gas/air or vapor/air mixture just ignites.

Thus the highest surface temperature of any equipment must always be less than the ignition temperature of the surrounding atmosphere.

Temperature classes T1 to T6 have been introduced for electrical equipment of Explosion group II. Equipment is assigned to each temperature class according to its maximum surface temperature.

Equipment that corresponds to a higher temperature class can also be used for applications with a lower temperature class.

Flammable gases and vapors are assigned to the relevant temperature class according to ignition temperature.

Definition of the temperature classes

Temperature class	Maximum surface temperature of the equipment	Ignition temperatures of combustible substances
T1	450 °C	>450 °C
T2	300 °C	>300 °C
T3	200 °C	>200 °C
T4	135 °C	>135 °C
T5	100 °C	>100 °C
T6	85 °C	>85 °C

Classification of gases and vapors into explosion groups and temperature classes

Explosion group	Temperature classes					
	T1	T2	T3	T4	T5	T6
I	Methane					
II A	Acetone Ethane Ethyl acetate Ammonia Benzene (pure) Acetic acid Carbon monoxide Carbon dioxide Methane Methanol Propane Toluene	Ethyl alcohol i-amyl acetate n-butane n-butyl alcohol	Petrol Diesel fuel Aviation gasoline Fuel oil n-hexane	Acetyl aldehyde Ethyl ether		
II B	Town gas (Illuminating gas)	Ethylene				
II C	Hydrogen	Acetylene				Carbon disulfide

For further information, please contact your local Siemens contact – see “Siemens Contacts Worldwide” in the Appendix.