

CHAPTER 12

ATEX DIRECTIVES AND EX EQUIPMENT

Lecture material for TTK 4175 Instrumentation Systems and Safety at the Department of Engineering Cybernetics, Norwegian University of Science and Technology (NTNU).

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The essence of managing ignition sources?

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Contents

12	ATEX and EX equipment	3
12.1	Abbreviations	3
12.2	What happens when explosive atmospheres ignite	3
12.3	The explosion triangle.....	4
12.3.1	Gas concentration and minimum ignition energy (gases)	4
12.3.2	Minimum ignition temperature vs minimum ignition energy (gases).....	5
12.3.3	Explosiveness of dust with minimum explosive concentration.....	6
12.4	Regulations and standards.....	6
12.4.1	ATEX directives.....	7
12.4.2	Norwegian regulations and regulator	7
12.4.3	EN IEC 60079	8
12.4.4	Outside Europe	8
12.4.5	Ex certification	8
12.5	Classification of Ex-zones.....	8
12.6	Coding of Ex-equipment.....	10
12.6.1	ATEX coding	10
12.6.2	EN IEC 60079 coding	10
12.7	Ex protection codes explained	12
12.7.1	Ex ia and Ex ib (intrinsically safe)	12
12.7.2	Ex d (flame-proof, gas only)	17
12.7.3	Ex e (prevent sparks, gas only)	17
12.7.4	Ex n (simple variant for motors, gas only)	18
12.7.5	Ex p (overpressure)	18
12.7.6	Ex m, Ex o, and Ex q (liquid or compound).....	19
12.7.7	Ex t (protection by enclosure, dust only).....	19
12.8	Comparison of codes.....	20
12.9	Labeling of Ex equipment.....	21
12.10	What if additional Ex-protection measures are needed?.....	23
12.11	Bibliography	24

12 ATEX and EX equipment

Did you know that many industrial plants, mines, silos containing grains and hay, and factories producing sugar can have explosive atmospheres? Explosive atmospheres are mixtures of flammable gases or dust in combination with oxygen. If ignited, they can cause fires and explosions.

This chapter explains the features added to electrical equipment to allow installation in areas with regular and rare explosive atmospheres. We will refer to such electrical equipment as Ex equipment, where Ex denotes design principles that prevent ignition and the possibility of an explosion.

Ex-equipment is electrical and electronic equipment with added features (“ex-protection”) that prevent contact with explosive atmospheres, prevent the generation of sparks, or prevent energy levels that can cause ignition.

The material of this chapter builds on the European ATEX directives and the EN IEC 60079 standard. The ATEX directives were named after the French term ATmosphères Explosibles, while EN IEC 60079 provides examples of how to implement the requirements. The ATEX directives also address ignition sources beyond electrical equipment. For example, they require pipes and rotating equipment to avoid excessively hot surfaces that could cause explosive atmospheres to self-ignite.

12.1 Abbreviations




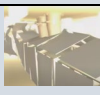

(samples)

ATEX	Atmosphères Explosibles
EX	Explosion-(proof)
IEC	International Electrotechnical Commission
LEL	Lower explosion limit
MEC	Minimum explosive concentration
MIE	Minimum ignition energy
MIT	Minimum ignition temperature
UEL	Upper explosive limit

12.2 What happens when explosive atmospheres ignite

It may be difficult to imagine what happens when an explosive atmosphere is ignited. A tiny spark from a hot surface or an electrical circuit can cause major accidents, as shown in the videos in Tab. 1.

Tab. 1. Short videos showing what happens when explosive atmospheres are ignited

	This YouTube video shows (as an animation) how dust generated in the wood fabrication industry can be ignited and cause an explosion.
	This YouTube video shows (as an animation) how flammable gases that leaked out at the Huskey Energy Refinery found an ignition source and ignited.
	This YouTube video shows (as an animation) how flammable gases that leaked out of a ruptured pipe at the Chevron Richmond Refinery were ignited.
	This YouTube video shows how sugar dust can be ignited and lead to an explosion. It is from a Sugar refinery in Savannah, Georgia.
	This YouTube video shows how hot work, like static electricity, can ignite flammable atmospheres. The storage tank is in Kansas, USA.

Therefore, the ATEX directives and the IEC standard mentioned above focus on classifying areas according to how often such atmospheres are present and how electrical devices and other equipment can be designed to prevent ignition.

12.3 The explosion triangle

Most of you may be familiar with the explosion triangle in Fig. 1. To create an explosion, three conditions must be fulfilled:

- Ignition source with sufficient ignition energy created by:
 - Open flames from fires or welding activities
 - Sparks from static electricity
 - Sparks or energy levels created from short circuits
 - Hot surfaces like pipes, rotating equipment, etc...
- Air with a minimum oxygen volume percentage
- Something combustible, like gases or dust

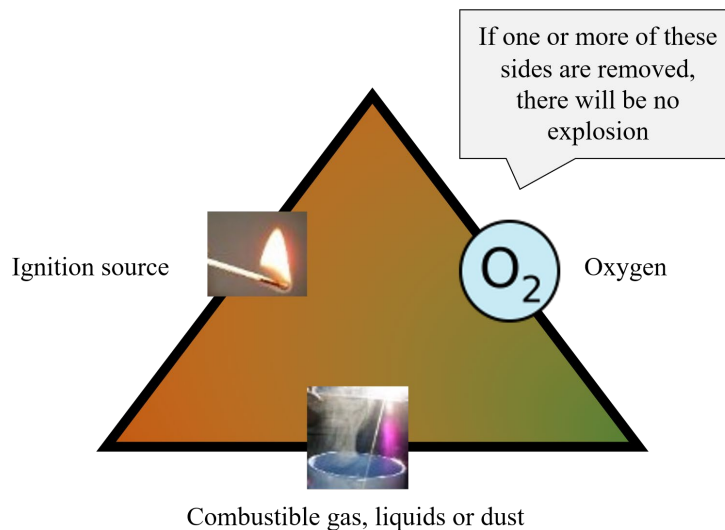


Fig. 1. Explosion triangle

Removing one or more sides of the explosion triangle prevents an explosion. What distinguishes an explosion from a fire (which relies on the same three factors) is how fast the energy expands after ignition, creating a shock wave.

The following section explains some concepts related to ignition sources and conditions for an explosive mixture. The focus is on atmospheres containing flammable gases. Still, most of the concepts are also relevant to dust, even if some details, e.g., how electrical equipment is protected, can be slightly different.

12.3.1 Gas concentration and minimum ignition energy (gases)

Not all mixtures of flammable gases can be ignited, even by an ignition source of sufficient energy. Each flammable gas has a concentration of air/gas that is either too thin to be ignited or too fat (condensed). The two limits are called the lower explosion limit (LEL) and the upper explosion limit (UEL), as shown with two vertical lines in Fig. 2. A gas concentration above the LEL but below the UEL is an explosive mixture.

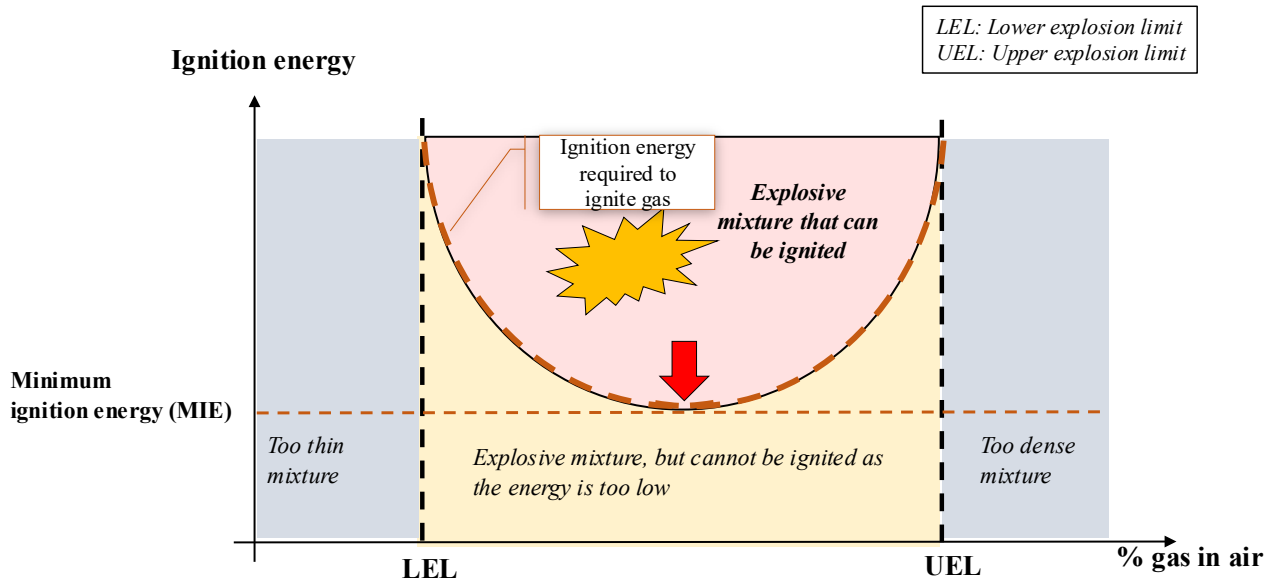


Fig. 2. Minimum ignition energy (MIE) vs. lower and upper explosion limits (LEL and UEL)

Adding an ignition source does not necessarily result in an ignition. From Fig. 2, we notice that a too-thin or too-thick mixture of gas in air will never be ignited, regardless of the energy level of the ignition source. The minimum ignition energy (MIE) is the energy required to ignite an explosive mixture. If the energy level of the ignition source is below the MIE, there will be no ignition. Tab. 2 identifies MIE for some selected gases measured in mJ. In contrast, a burning stearin candle can produce 80,000 MJ per second.

12.3.2 Minimum ignition temperature vs minimum ignition energy (gases)

High temperatures may also lead to energy levels above MIE, not only open flames and sparks. Self-ignition may occur if the temperature exceeds such a threshold. Therefore, the equipment must also have a surface temperature below the gas's self-ignition temperature. We refer to this temperature limit as the minimum ignition temperature (MIT) and Tab. 2 identifies MIE and MIT for some selected gases

Tab. 2. MIT and MIE for selected gases

Gas	Formula	Density (gas vs air)	LEL (%)	UEL (%)	Minimum ignition temperature (MIT) °C	Minimum ignition Energy (MIE) (mJ)	Gas group
Methane	CH ₄	0.5	5.0	15.0	595	0.28	I
Hydrogen	H ₂	0.1	4.0	75.6	560	0.019	IIC
Ethane	C ₂ H ₆	1.05	3.0	15.5	515	0.25	IIA
Ethylene	C ₂ H ₄	1.0	2.3	32.4	425	0.07	IIB
Butane	C ₄ H ₁₀	2.1	1.5	8.5	365	0.25	IIA
Propane	C ₃ H ₈	1.6	2.1	9.5	470	0.26	IIA
Acetylene	C ₂ H ₂	0.9	1.5	80.0	305	0.019	IIC
Crude oil (gas)			1	10			

It may be surprising (and feel safe) that the temperatures seem higher than those in a kitchen oven. However, compared to temperatures of 600-1200 °C in the open flame of a burning candle, they are not that extreme. Consequently, equipment (electrical or non-electrical) located in areas with potentially explosive mixtures must

have a surface temperature lower than MIT (with a good margin). We will later learn that all equipment must have a temperature class that guarantees the temperature stays below MIT.

12.3.3 Explosiveness of dust with minimum explosive concentration

Ignited dust can create an explosion if the following criteria are present:

- Existence of combustible dust particles
- Dust is suspended in the air above its minimum explosive concentration (MEC) (see below)
- The space is confined, partially or fully, so that pressure buildup can happen quickly
- An ignition source is present (above the minimum ignition temperature (MIT) or minimum ignition energy (MIE)).

An internet search suggests MEC, MIE, and MIT for the four dust types shown in Tab. 1.

Tab. 3. Minimum

Dust type	MEC	MIE	MIT
Sugar	≈ 135 g/m ³	≈ 20-60 mJ	370 °C
Cereal dust:	40-150 g/m ³		220-250 °C
Metal dust	≈ ca. 50 g/m ³	Not found	Not found
Wood dust	≈ ca. 50 g/m ³	≈ 20-60 mJ	Not found

Despite the lack of stable upper explosive concentrations, the literature reports that extremely dense dust can become too rich (too dense) to explode.



Fig. 3. Relationship between EU Directives and Norwegian regulations

12.4 Regulations and standards

Regulations related to the design, installation, and maintenance of Ex-equipment are set out in the EU ATEX directives and the corresponding Norwegian regulations, as illustrated in Fig. 3, and explained in more detail in the following sections.

12.4.1 ATEX directives

The ATEX directives refer to two specific EU directives:

- **The ATEX “Equipment Directive”:** ATEX 2014/34/EU (2014) focusing on the design of equipment and protective systems intended for use in potentially explosive atmospheres. The directive covers requirements for electrical and non-electrical equipment located in explosive atmospheres. For electrical equipment, it is specified which Ex design principles are permitted in which Ex zones. The primary users of this directive are manufacturers who design equipment for use in explosive atmospheres. Still, those who engineer and operate the plants must know how to select appropriate protection for a specific site and application.
- **The ATEX “Workplace Directive” (or User Directive):** ATEX 1999/92/EC (1999) focusing on requirements that can protect workers potentially at risk from explosive atmospheres, using risk analysis, and classifying areas into Ex-zones depending on how often explosive atmospheres are present. The primary users of this directive are engineering companies and facility owners, who need to ensure that zones are correctly identified and reassessed during reconstruction, and that equipment placed in the various zones has the required ex-protection.

The relationship between the two directives can be explained (a bit simplified) as follows:

- **Target group:**
 - The ATEX Equipment Directive primarily concerns equipment design, and is primarily used by manufacturers that develop equipment for use in areas with explosive atmospheres
 - The ATEX User Directive focuses on how to manage the risks from explosive atmospheres, and is primarily relevant for end users, meaning those operating plants and facilities, and system integrators (engineering companies) that are engaged in construction and rebuilding such.
- **Type of directive**
 - The ATEX Equipment Directive is a maximum directive, meaning that European countries cannot add extra requirements.
 - The ATEX User Directive is a minimum directive, meaning the same countries are allowed to have additional rules.

12.4.2 Norwegian regulations and regulator

The two ATEX directives have been adapted in two distinct Norwegian regulations:

- FUSEX (2017): The equipment and safety systems for use in explosive atmosphere areas
- FHOSEX (2017): The regulation of health and safety in areas with explosive atmospheres

Two National authorities that are responsible for the regulations are:

- The Norwegian Directorate for Civil Protection (DSB): DSB's responsibility area is wide, but in this context, its role as authority for land-based industries producing, handling, storing, and transporting hazardous (including explosive) materials is most relevant. Their follow-up of FHOSEX is explained in a guideline on the [DSB webpage](#).
- The Norwegian Ocean Industry Authority (HAVTIL): HAVTIL is responsible for offshore industries such as petroleum, CO₂ transport and storage, seabed mining, wind parks, and some of them connected to onshore facilities. The following [regulations](#) are examples of where FUSEX and FHOSEX are addressed:
 - Their facilities regulation §10 on ignition source control and § 5 on design of facilities
 - Technical and operational regulations §10 on ignition source control and §6 on design of facilities

12.4.3 EN IEC 60079

The European Commission lists EN IEC 60079 (20xx) (consisting of 20+ parts) is a harmonized standard for the ATEX directives. Some parts focus on the detailed requirements for electrical equipment placed in explosive atmospheres, while other parts address specific ex-protection methods, approaches to classification ex-zones, inspection, and maintenance. We will not go into more detail here, but the implications of using the standard are mentioned later.

Remark: We may sometimes skip “EN” in the name of the standard in this chapter, but it still refers to the same standard.

12.4.4 Outside Europe

Similar regulations to the ATEX directives exist outside Europe. For example, products sold in the US market must comply with the US Occupational Safety and Health Administration (OSHA) regulations. Other countries also have regulations that must be complied with. Most regulations will accept equipment developed in accordance with IEC 60079, since it is an international standard, but additional labeling may be required to align it with national or regional requirements.

12.4.5 Ex certification

Products sold on the EU market must be certified by an EU-approved notified body. The complete list of notified bodies (i.e., companies) is in the EU New Approach Notified and Designated Organization ([NANDO](#)) database. A [search setup](#) can be configured to identify notified bodies that can certify ATEX equipment.

The International Electrotechnical Commission (IEC) has developed a global system for the certification of Ex-equipment called [IECEX](#). Selected international IEC standards are applied for the certification. As IEC 60079 is harmonized in the EU and internationally accepted, many certification processes are based on this. Many companies in the NANDO database have also been approved for IECEX certification.

12.5 Classification of Ex-zones

One task of the ATEX workplace (or user) Directive is to divide the plant into zones based on the degree of exposure to explosive atmospheres. We sometimes use the term ex-zone to avoid confusion with other uses of the term "zone".

A risk analysis is required to evaluate exposure to gases or dust in various areas of a facility during normal operation, resulting in a zone map that identifies all zones and their outreach. IEC 60079-10 specifies how such an analysis may be carried out. For explosive atmospheres involving gases, vapor, and mist, we distinguish between the following zones:

- **Zone 0:** An area in which an explosive atmosphere consisting of a mixture of flammable substances with air in gas, vapor, or mist is present continuously, for long periods, or frequently.
- **Zone 1:** An area in which an explosive atmosphere consisting of a mixture of flammable substances with air in the form of gas, vapor, or mist is likely to occur occasionally during regular operation.
- **Zone 2:** An area in which an explosive atmosphere consisting of a mixture of flammable substances with air in the form of gas, vapor, or mist is not likely to occur in regular operation or persist over a short period.

For explosive atmospheres involving dust, the Ex-zones are:

- **Zone 20:** An area in which an explosive atmosphere in the form of a cloud of combustible dust in air is present **continuously**, for long periods, or frequently.
- **Zone 21:** An area in which an explosive atmosphere in the form of a cloud of combustible dust in the air is likely to occur occasionally during regular operation.
- **Zone 22:** An area in which an explosive atmosphere in the form of a cloud of combustible dust in air is **not likely** to occur in regular operation, but, if it does happen, will persist for a short period only.

What is continuous/frequent, occasional, and not likely is shown in Tab. 4 along with some practical examples of a location where this zone may be relevant

Tab. 4. Zones – examples

Zone	Likelihood of explosive atmosphere	Examples
Zone 0	Continuous/frequent presence Emissions occur continuously or for long periods, typically > 1000 hours per year or more than 10% of total process time	Inside vessels/tanks Liquid surfaces
Zone 1	Occasionally Emissions occur periodically or randomly during regular operation, typically >10 and < 1000 hours per year	Ventilation ducts from storage tanks Bottling and filling sites Stuffing box (around shafts) Flexible pipes
Zone 2	Not likely/short period Emissions are not expected to occur during regular operation, but exceptional and short-term emissions, typically <10 hours per year and < 2 hours per exposure	Flanges Gaskets Connectors (pipelines) Valves

All Ex-zones are considered hazardous areas, while those that are not are classified as unclassified or non-hazardous areas.

An example of a zone map for a gas station is shown in Fig. 4. From this drawing, we can observe that:

- Zone 0 is inside the petrol storage tank (underground).
- Zone 1 is around each ventilation duct from the tank and at the petrol pump station.
- Zone 2 surrounds zone 1 areas plus the connection point for filling the storage tank.

The ATEX directive provides rules for sizing zones and creating zone maps. We are not focusing on how the zones are established, but on how the map influences the choice of Ex-protection of electrical equipment.

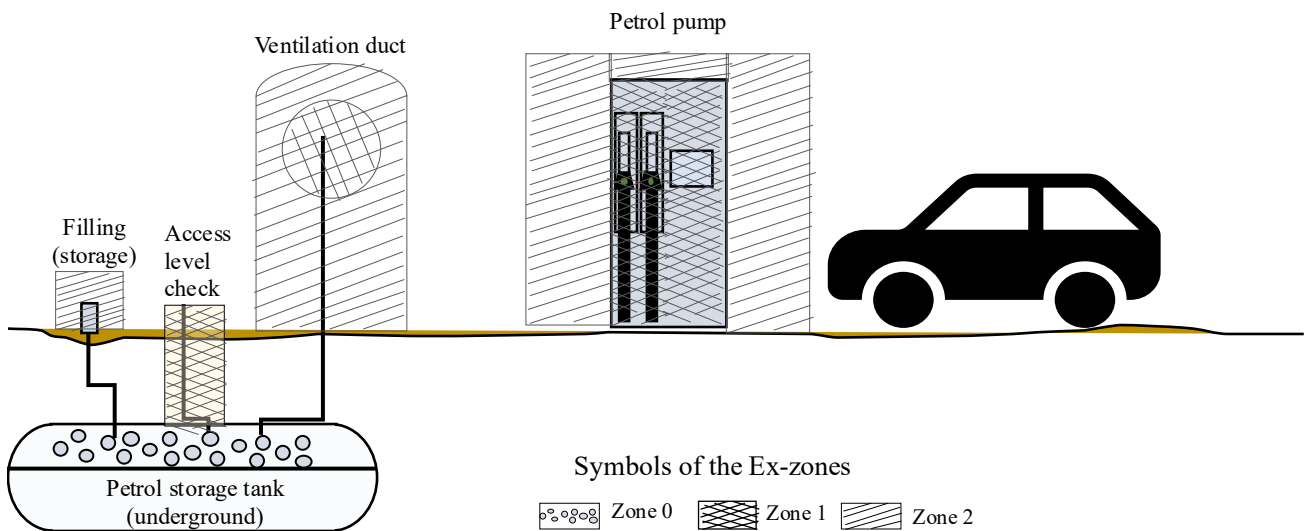


Fig. 4. Example of an Ex-zone map (Petrol station)

12.6 Coding of Ex-equipment

Coding of Ex-equipment is vital for understanding where the equipment can be used and how it is designed to prevent the ignition of explosive gases or dust. ATEX directives and EN IEC 60079 provide their own coding, with some overlap, and the codes are found on the Ex-label and the Ex-certificate. Relevant notified bodies in the EU NANDO database check and approve the products against the ATEX directives, and organizations registered in IECEx do the same based on EN IEC 60079.

12.6.1 ATEX coding

The ATEX equipment directive applies three code categories, as shown in Tab. 5:

- Equipment group coding identifies the location in which the equipment is installed.
- Equipment category coding identifies the Ex zone in which the equipment can be installed.
- Atmosphere coding identifies whether gases or dust are involved.

Tab. 5. ATEX coding of environment and explosive atmospheres

Equipment group (where)	Equipment category (in which zone)	Atmosphere/environment
I: Mine (explosive gases)	1: For use in zone 0 (20)	G: Gas
II: Elsewhere (explosive gases)	2: For use in zone 1 (21)	D: Dust
III: Dust	3: For use in zone 2 (22)	

Electrical equipment can discharge energy, so selecting a design principle that prevents ignition of an explosive atmosphere is necessary. These principles are often referred to as ex-design principles. Several design principles are available, and the Ex-marking/label mounted on the equipment, along with the equipment's Ex certificate, must comply with this information. Unfortunately, the ATEX Equipment Directive and IEC 60079 (the harmonized standard) classify information relevant to Ex equipment using different coding. As most Ex-certificates present both code sets, we must explain both.

12.6.2 EN IEC 60079 coding

EN IEC 60079 applies four code categories:

- **Temperature class**, identifying the maximum surface temperature the equipment can have.
- **Equipment protection level (EPL)**, identifying the inbuilt fault tolerance, or robustness, that the equipment provides.
- **Protection method** (with ex-protection coding), identifying the primary design principle of the equipment to prevent ignition.
- **Gas group**, identifying the energy level needed to ignite the gases.

Equipment installed in a classified area, regardless of whether it is zone 0, 1, or 2 (alternatively, 20, 21, or 22), must have a surface temperature below the maximum ignition temperature (MIT). IEC 60079 identifies six temperature classes, T1 to T6, that correspond to six levels of surface temperatures, as shown in Tab. 6. Equipment must identify the temperature class in the Ex-label and Ex certificate. The temperature corresponding to T4, marked in orange in the table, is one of the most commonly used temperature classes.

Tab. 6. Temperature classes

Temperature class	T1	T2	T3	T4	T5	T6
Max surface temperature (°C)	450	300	200	135	100	85

Equipment installed in classified zones (zones 0, 1, 2, or, alternatively, 20, 21, 22) must be robust against faults, here referring to faults that could lead to the loss of ex-protection. Tab. 7 identifies these as Ga, Gb, and Gc, alternatively Da, Db, and Dc for dust, under the equipment category heading.

Tab. 7. EN IEC 60079 coding of Ex Equipment categories

Equipment protection level (EPL)	Explanation
Ga (Da)	Very high protection. Must tolerate two faults (required for zone 0 (20))
Gb (Db)	High protection. Must tolerate single fault (required for zone 1 (21))
Gc (Dc)	Enhanced protection (required for zone 2 (22))

In the following, we will focus primarily on codes that apply to equipment installed in areas with gases, and comment on this towards the end of the chapter on what codes apply to equipment in areas with dust.

Tab. 8. EN IEC 60079 coding of Ex protection methods

Protection method	Ex protection code	Description	Zone	Equipment protection level (EPL)
Isolation	Ex o	Liquid immersion	0	Ga
	Ex p	Pressurized closure	1	Gb
	Ex q	Powder filling	1	Gb
	Ex m	Encapsulation (solidified)	1	Gb
	Ex t	Ingress tight (dust only)	0-2	Ga-Gc
Encapsulation	Ex d	Flameproof enclosures (gas only)	1	Gb
Design	Ex e	Increased safety (no sparkling)	1	Gb
	Ex n	Type of protection (for motors)	2	Gc
Restricted energy	Ex ia	Intrinsic safe	0	Ga
	Ex ib	Intrinsic safe	1	Gb
Special	Ex s	Special protection	0-2	Ga-Gc

Protection methods categories are based on some general design principles for electrical equipment to eliminate the possibility of being an ignition source:

- Prevent the energy level in the electrical circuit(s) from ever reaching the minimum ignition energy of the explosive mixture
- Prevent discharge
- Prevent the atmosphere from being in contact with the electrical circuit
- Allow the ignition inside the equipment, but reduce the energy to a level below the minimum ignition energy before reaching contact with the environment

Tab. 8 identifies five protection methods: isolation, encapsulation, design, restricted energy, and special. Ex protection codes such as o, p, d, e, ia, etc., identify how the protection is implemented. The same table also shows which Ex-zone each protection type applies to. Finally, the same table specifies the zone in which the equipment can be installed and the level of fault tolerance to be implemented.

Tab. 9 shows how IEC 60079 classifies gases by the minimum ignition energy required. Equipment installed in an area for a given gas group must have a maximum generated transient energy level below this value.

Tab. 9. EN IEC 60079-11 coding of environment and explosive atmospheres

Gas group	Description	Gases with lower ignition energy
I	Mines	Methane
IIA	Gases w/ min ignition energy higher than 200 μ J (0.2mJ)	Propane, Ethane Acetone, Methanol, Methane
IIB	Gases w/ min ignition energy between 60 μ J (0.06mJ) and 200 μ J (0.2 mJ)	Ethylene

IIC	Gases w/ min ignition energy less than 60 μJ (0.06mJ)	Hydrogen Acetylene
III	Dust particles	Dust

12.7 Ex protection codes explained

The Ex-protection codes in Tab. 8 and Tab. 12 are explained in detail in various parts of IEC 60079, listed in Tab. 10. Additional ex-protection codes may be found in other parts; however, the listed ones are among the most applied.

Tab. 10. IEC 60079 references for details about the various Ex protection codes

Ex protection code	Description	IEC 60079 reference
Ex o	Liquid immersion	IEC 60079-6
Ex p	Pressurized closure	IEC 60079-2 & IEC 60079-13
Ex q	Powder filling	IEC 60079-5
Ex m	Encapsulation (solidified)	IEC 60079-18
Ex d	Flameproof enclosures (gas only)	IEC 60079-1
Ex e	Increased safety (no sparkling)	IEC 60079-7
Ex n	Type of protection (for motors)	IEC 60079-15
Ex ia	Intrinsic safe (tolerates two faults)	IEC 60079-11
Ex ib	Intrinsic safe (tolerates single fault)	IEC 60079-11
Ex s	Special protection	IEC 60079-33
Ex t	Protection by enclosure (dust only)	IEC 60079-31

For specific cable requirements related to Ex-equipment, including cable entries, insulation, and dimensioning, refer to IEC 60079-14.

12.7.1 Ex ia and Ex ib (intrinsically safe)

Ex i represents a protection principle referred to as an intrinsically safe (IS) design principle, the letter “i” meaning “intrinsically”. In contrast to the other protection principles, this protection does not limit itself to individual devices but extends to the entire electrical circuit, including signaling transfer, terminations, power supply, and earthing systems, and the aim is to design this totality in a manner where the energy at any point in the (ex) hazardous zone is kept below the threshold by which the flammable gas atmosphere can be ignited, i.e., below the minimum ignition temperature (MIE).

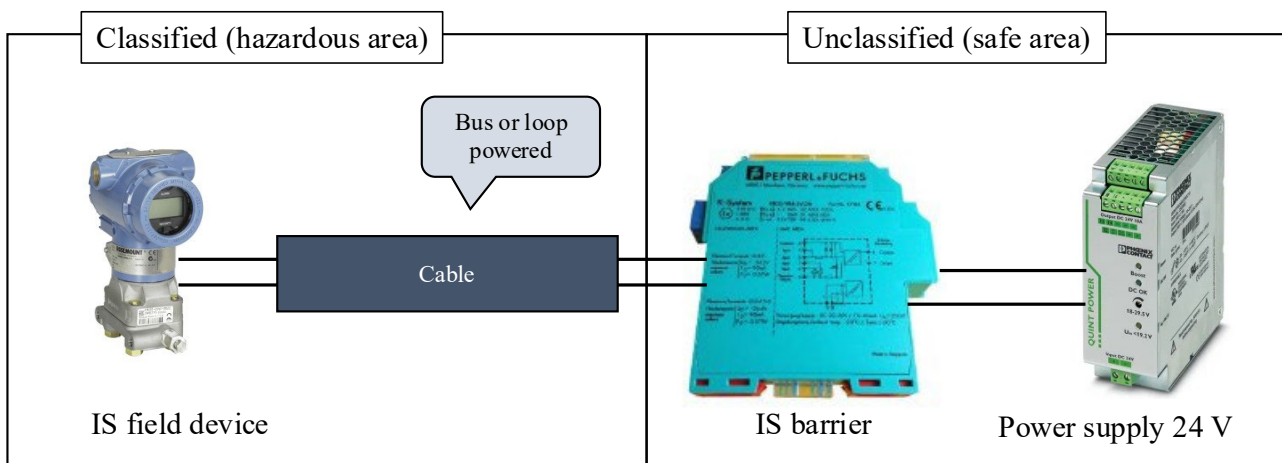


Fig. 5. Ex i circuit with IS barrier

The ex-protection is therefore ensured by:

- Performing a proper dimensioning of the whole electrical circuit, so that the applied voltage and currents to the connected field device never exceed the threshold
- Adding an energy-restricting component, named IS barrier, placed in the non-hazardous zone, that automatically “re-routes” any currents or voltage levels beyond the threshold away from the hazardous zone and into an IS earthing system.

There are three types of Ex i circuit variants or types:

- Ex ia that can be used in zone 0
- Ex ib that can be used in zone 1
- Ex ic that can be used in zone 2

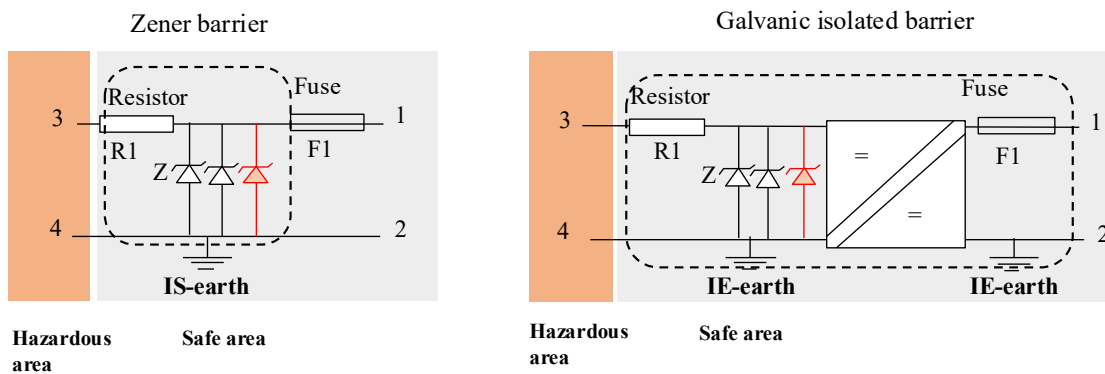
Our focus is limited to Ex ia and Ex ib, as they are the most common and always include IS barriers.

IS barrier

The IS barrier, itself being located in the safe (non-hazardous zone) prevents excessive currents and voltage levels supplied to the circuit and connected devices located in hazardous (ex) zones as illustrated in Fig. 5.

The typical layout of an IS barrier includes an arrangement of resistors, fuses, and Zener diodes, and in some cases, also a galvanic isolator, as shown in Fig. 6. There are some variants of these, for example, with two sets of diodes, each in opposite direction, where the branch midpoints connect to IS (or IE) earth. Many IS vendors add an illustration of the specific arrangement chosen at the IS barrier enclosure, as shown in Fig. 5.

Ex ia: Three zener diodes/fault tolerance of two



Ex ib: Two zener diodes/fault tolerance of one

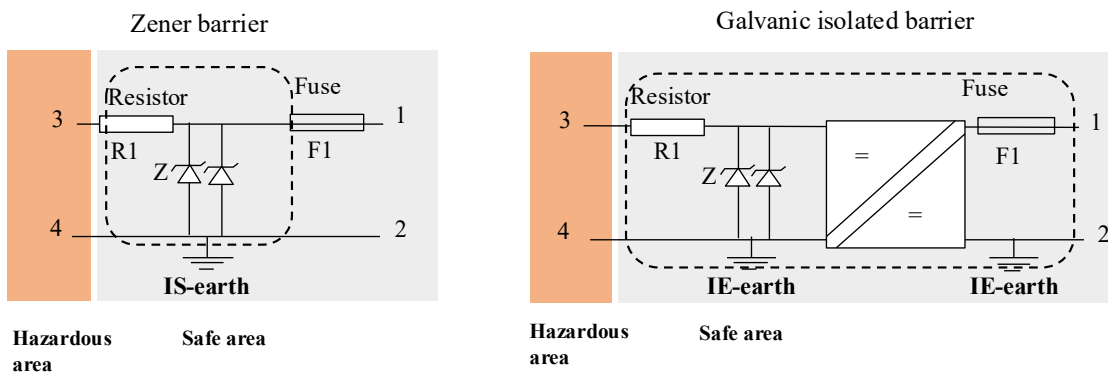


Fig. 6. Ex ia and Ex ib IS-barriers

The specific roles of the listed IS barrier components are:

- Resistor: Persistent (and dimensioned in) restrictor of current under normal operating conditions

- Zener diodes: Instantly reroute excessive currents, i.e., beyond those that can generate energy levels beyond MIE, to the IS or IE earthing system
- Fuse: Protection of Zener diodes from unnecessary stress
- Sometimes: Galvanic isolator, separating the electrical circuits of the safe and hazardous zones fully

Consequently, and as illustrated in Fig. 6, there are two types of IS barriers:

- Zener barrier: IS-barriers with no galvanic isolation. In this case, it is necessary to have a dedicated, protected IS earthing system for the entire circuit, including the portion in the hazardous area.
- Galvanic isolated barrier: The barrier has, as the name indicates, a galvanic isolation in addition to the Zener diodes. In this arrangement, no dedicated IS earthing to the hazardous area is required, and IE earthing system is applied.

The main distinction between Ex ia and Ex ib is the fault tolerance built into the IS barrier to accommodate the increased risk of explosive atmospheres in zone 0 compared to zone 1. As illustrated in Fig. 6: Ex ia applies an IS barrier with fault tolerance of two (three Zener diodes), while Ex ib applies IS barriers with fault tolerance of one with two Zener diodes. As the IS barrier is located in the safe (non-hazardous) zone and does not require any ex-protection, its marking is placed in brackets: [ex ia] or [ex ib].

Field instrument/devices

The connected field instrument (in the hazardous area) is being labeled for installation in a circuit with an Ex ia or Ex ib barrier. The field device is marked for explosive gaseous or dust atmospheres in which it can be installed, meaning the device's electronics do not rely on current or voltage levels below the ignition-energy thresholds. Measures are also in place to ensure the surface temperature remains well below the gas type's self-ignition temperature.

Note that:

The field device itself (such as the transmitter) will be marked as Ex ia or Ex ib, depending on the chosen IS barrier. The IS barrier itself, which is placed in a safe/non-hazardous area, is marked with [Ex ia] or [Ex ib].



Cables and termination

Careful, circuit-specific calculations are necessary to ensure that the entire circuit, given the cable length, does not generate excessively high energy levels, particularly for power loops when a power supply for the field device is also provided alongside the signal transmission.

Ex i circuits can accommodate various cable types, including twisted two-pair power loops for 4–20 mA, fieldbus systems (both standard and power-looped, such as PROFIBUS PA), and Ethernet-based systems (standard and power-looped, e.g., Ethernet APL). Wires applied for signaling and/or power supply in an IS circuit are referred to as IS wires and/or IS cables.

When the power supply to the field device is separate from the signal—such as in standard fieldbus and Ethernet installations—each circuit requires its own intrinsic safety (IS) barrier.

IEC 60079-14 identifies the more specific requirements for cables and terminations. For example:

- The same cables shall not contain IS and non-IS wires, and the IS cables shall be clearly marked. IS wires must be segregated and clearly marked at their termination points.

- Terminations of IS wires, i.e., at the point they are plugged in or fastened at their end, must be at a distance of at least 50 mm (2 in) from the terminations of non-IS circuits, or adequate separators (e. g., grounded metal partitions) must be used.
- Terminations of wires for a specific IS circuit should be separated by at least 6 mm from other IS circuit terminations.

Dimensioning an Ex-i circuit

Dimensioning an Ex-i circuit requires detailed analysis with special competence. The need for Ex-i loop calculations also applies to Fieldbus systems, where power and communication are carried on the same cable pair. For Industrial Ethernet over Ethernet-APL, however, these calculations are generally not required at the field-device level, as the necessary intrinsic-safety margins are incorporated into the standardized trunk and spur specifications, and the intrinsic-safety functions are integrated into the APL field switches.

A very simplified example is shown in Fig. 7 for a power-looped 4-20 mA cable.

- The starting point is to consult the manufacturer's certification about the maximum voltage, notation U_I , and current level, notation I_I , that apply for where the equipment can be used (i.e., for what types of explosive atmospheres). We assume that the certificate states $U_I = 28\text{ V}$ and $I_I = 170\text{ mA}$, which may have been determined from a $PI = U_I * I_I$ curve, where PI must always be less than the value required for the applicable gas type (or dust group). In this example, we assume it is set relative to the IIIC curve.
 - The voltage and currents applied to the IS barrier, with notation U_O and I_O , must always be lower than U_I and I_I , to always be on “the safe side”.
 - However, a safety margin is applied when selecting Zener diodes, so that U_Z , the voltage level at which the Zener diodes start to open (for rerouting excessive currents), always stays below U_I and I_I . This margin is sometimes 10%. We assume that $U_Z = 26\text{ V}$.
- The next step is to determine the resistance of each part of the electrical circuit, including the barrier, the cabling, and the field device(s) and associated components. In this example, we assume the initial calculations suggest $1315\ \Omega$:

Component	Resistance (Ohm - Ω)
Internal resistance input card	10
Measurement resistance for converting mA to V (A/D converter)	250
IS barrier	420
Cabel	10
Transmitter	625
Total:	1315

- We now need to check if the field device can transit its maximum measurement value (20 mA), without exceeding the U_Z of the IS barrier where the diodes start to open: In our example, the condition is violated: $20\text{mA} * 1315\ \text{Ohm} = 26.3\text{ V}$. We cannot design a circuit that always leaks current during normal operation.
- We therefore need to find ways to reduce the resistance of the loop, and it seems that the A/D converter is the only practical choice:
 - Assume that we can reduce the A/D resistance from $250\ \Omega$ to $62.5\ \Omega$. The total resistance is then $1112.5\ \Omega$.
 - However, the reduction comes with a resolution “cost”: With 20 mA as the maximum received value, the corresponding voltage available for the A/D converter is reduced from $20\text{mA} * 250\ \Omega = 5\text{V}$ to $20\text{mA} * 62.5\ \Omega = 1.25\text{ V}$. As we will see, it has an implication for the resolution on the digitally converted value of the analog measurement.
 - We assume that the A/D converter delivers the converted analog measurement as a 10-bit message:
 - Assume that the A/D converter is designed for an optimal resolution when supplied with power in the range of 0-10V. On the analog side, it means a resolution of $10\text{V} / 2^{10} \approx 0.01\text{V}$ for each of the 1024 steps.

- Even with the initial 5V available for the A/D converter, the resolution is lower, i.e. $5V/0.01 = 512$ steps.
- With only 1.25 V supplied to the A/D converter, it is further reduced to $1.5V/0.01V \approx 128$ steps (Besides dimensioning the IS circuit, it is important to adhere to requirements in IEC 60079-14 concerning (among many topics) requirements for the installation.

In conclusion, we can install the device, but the resolution of the digitally converted measurement becomes poor.

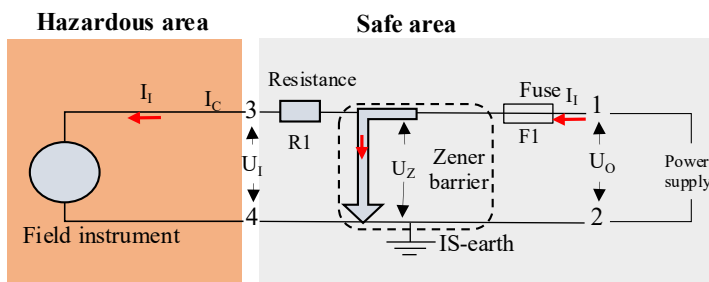
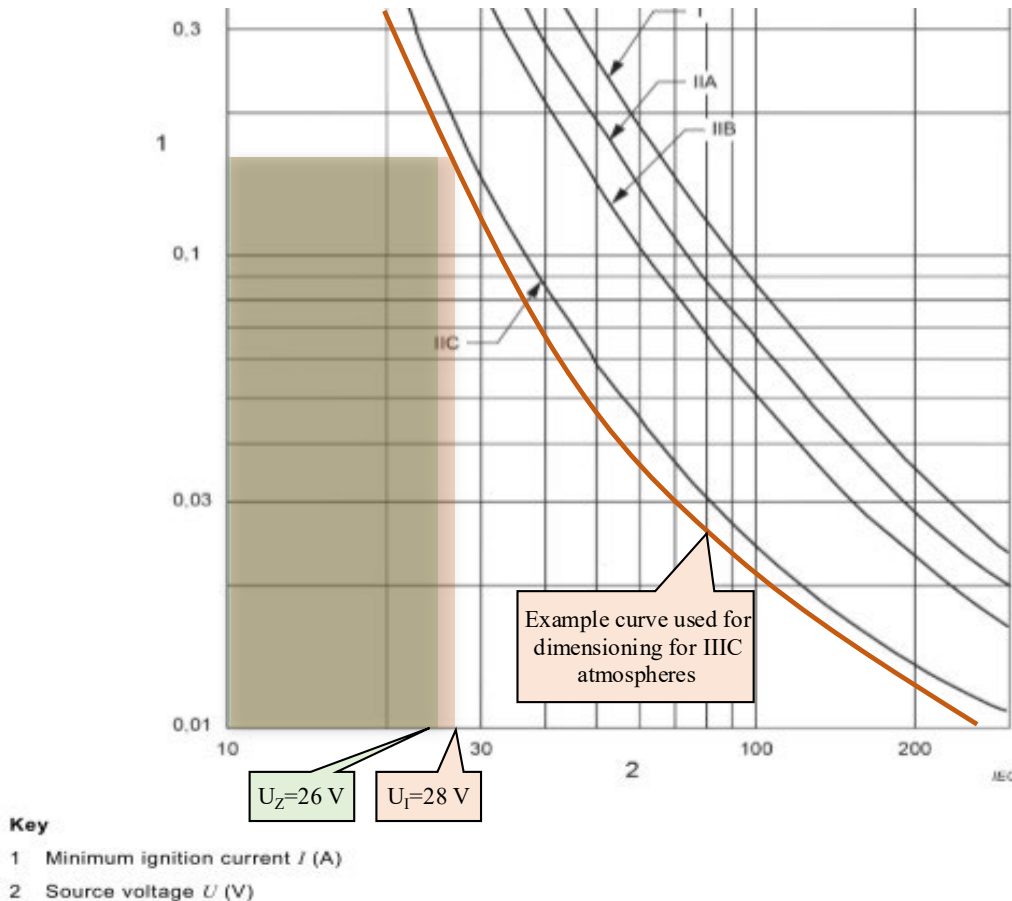


Fig. 7. Simplified ex i circuit. Curve snip from IEC 60079-14 indicating maximum I and U without margin (green) and with margin (red)

Other issues and choices may also arise during dimensioning and are not covered here. In all cases, it is necessary to redo such analyses if the installation is subject to changes, such as replacing the cable, changing cable lengths, or replacing the field device.

12.7.2 Ex d (flame-proof, gas only)

Ex-d equipment is designed to tolerate an internal explosion within the equipment housing in the presence of explosive atmospheres. Applies only to gas environments, and not to dust. The housing is designed to reduce the energy from the explosion to a level that cannot ignite outside. This principle relies on two design measures:

- A strong housing that can withstand the internal explosion
- Flame paths, for example, across screwed paths

Examples of where the flame paths are found and the principle for how the flame paths work are shown in Fig. 8.

An additional challenge with Ex d equipment and junction boxes is the need to use special Ex-proof cable glands. The cable gland is the component used to secure and seal cables as they pass into electrical enclosures or equipment. When used for Ex d equipment, the cable gland becomes an integral part of the flameproof enclosure and is therefore more complex than other cable entries.

- The part of the gland that fastens the cable with threaded joints also has a function as a flame.
- Another part of the gland ensures that no gas can enter and migrate between voids (Norwegian: hulrom) within the cable layers. The cable gland provides protection against gas migration by a combination of mechanical sealing using compression arrangements that secure each cable layer individually (outer sheath, armor, and inner sheath) without clamping the electrical conductors, and (as needed) by compound sealing for the cable wires.

12.7.3 Ex e (prevent sparks, gas only)

Ex e is called increased safety and represents a collection of design measures to prevent sparks from being generated in the circuit. Measures include:

- Larger margins (distances) between terminals/connection points for wires and wire screens.
- Measures to avoid the temperature inside the equipment or at the surface increasing above its temperature class
- Intrusion protection (IP) grade 54, which protected against intrusion of dust and water spray
- Special cable nipples for routing cables into the equipment
- Plugs for drainage of any humidity

Cable nipples, compared to cable glands, do not have the same gas-tight requirements.

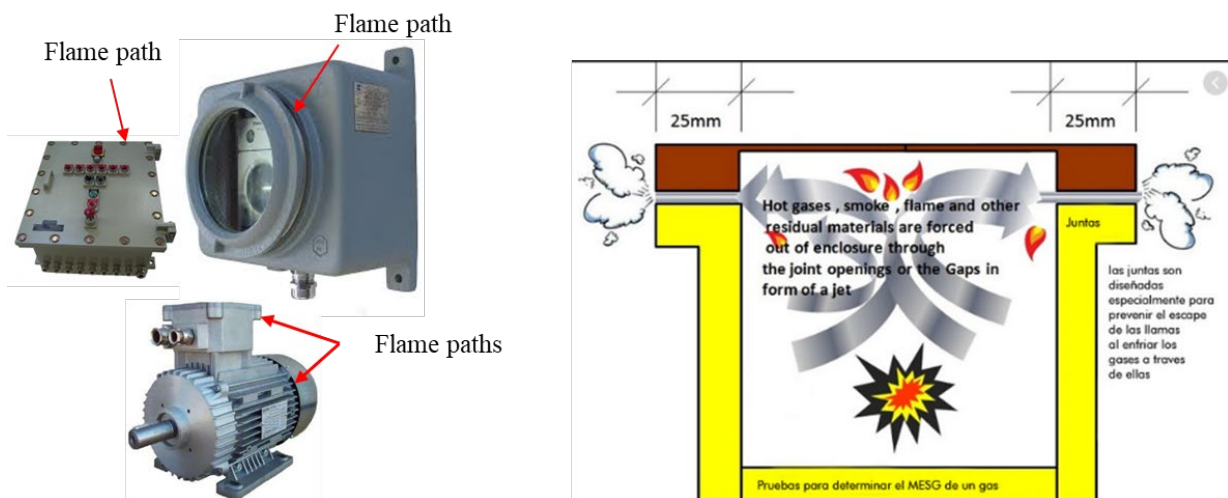


Fig. 8. Ex d encapsulation with flame paths

Ex e is most commonly used for junction boxes that connect and reroute cables and wires in hazardous areas and for lighting fixtures. Ex e can also be achieved for smaller motors. An example of an Ex-e junction box is shown on the left side in Fig. 9.

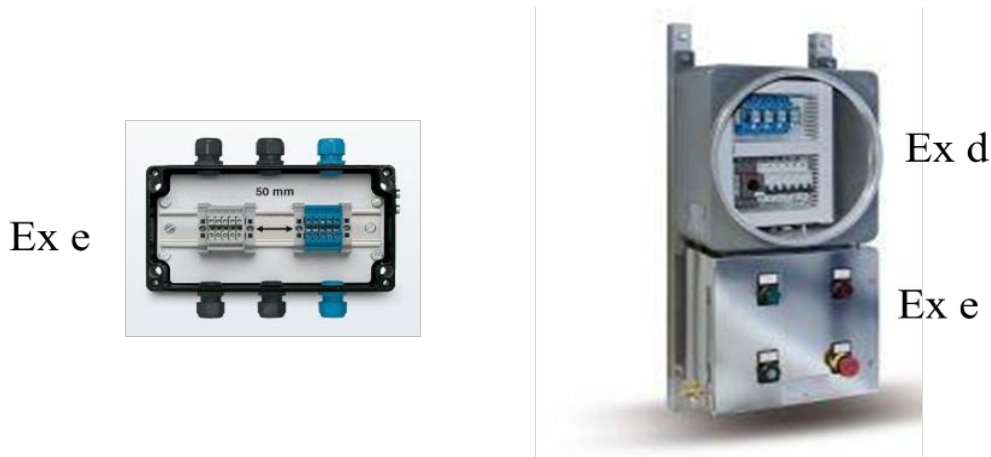


Fig. 9. Ex e junction box (left) and Ex e junction box combined with Ex d (right)

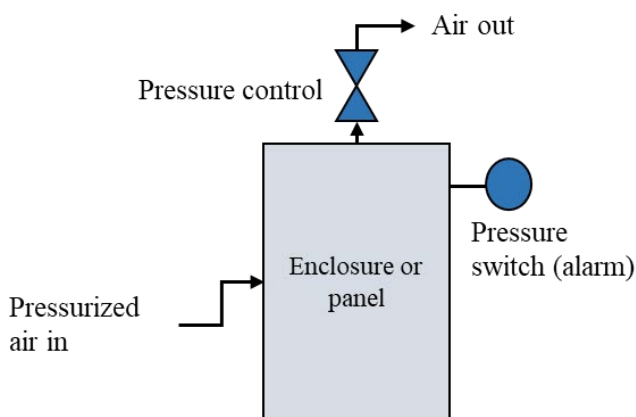
Ex-e junction boxes are often combined with Ex-d equipment, with cables first entering an Ex-e junction box and then terminated there to avoid direct entries to Ex-d enclosures, which are more costly and complicated. An example of such a setup is shown to the right in Fig. 9.

Also, motors can be designed as Ex e, meaning that specific design measures have been taken to prevent sparks or excessive heat from being generated even under certain fault conditions by using:

- IP protection grade of IP54 for motor junction boxes
- Distance between stator and rotor to fulfill the minimum requirements in IEC EN 60079-7

12.7.4 Ex n (simple variant for motors, gas only)

EX n is a simpler variant of the Ex e motor, in which sparks can be prevented during regular operation but not during fault conditions. This relaxation is allowed because zone 2, where the motor can be used, seldom contains explosive atmospheres.



Examples



Fig. 10. Ex p enclosure examples

12.7.5 Ex p (overpressure)

Ex p is a protection method that applies a slight overpressure to a confined enclosure or room, sufficient to prevent the intrusion of gases from the outside atmosphere. This type of protection is often applied to equipment

rooms and larger control panels that must be in hazardous areas and to compressor and generator hoods (enclosures), as shown in Fig. 10.

There are three sub-categories of Ex p applied for environments with explosive gases, while for dust environments, only Ex p is applied:

- **Ex px:** Zone 1. Strict requirements for pressure monitoring, automatic shut-off, and use of clean air and inert gas
- **Ex py:** Zone 1. Slightly less stringent requirements compared to px, such as tolerating some pressure variations. Use in less critical areas
- **Ex pz:** Zone 2. Reduced monitoring requirements. May require gas detection if air is taken from an area where gas could be present.

Ex py and Ex pz are perhaps the most common implementations. Here, the air distribution system supplies air at a specified pressure into the enclosure, and the pressure inside is controlled by a valve at the outlet. An alarm is raised if the pressure falls below a specific setpoint, and the electrical equipment inside is shut down, and power is isolated.

12.7.6 Ex m, Ex o, and Ex q (liquid or compound)

Ex m, ex o, and ex q are three principles where electrical parts are encapsulated or immersed to prevent contact with explosive atmospheres.

Each of them can be explained as follows:

- Ex m protection method encapsulates electrical components with a compound or resin. The principle can be used for, e.g., the solenoid part of solenoid valves, as shown in Fig. 11. An internet search also reveals that Ex m is used for cameras.
- Ex o protection method immerses the electrical parts in liquids to prevent contact with explosive atmospheres. An earlier version of IEC 60079 specified oil as the liquid (hence the “o”), but the recent update has chosen the more general term “liquids”. The design principle is most commonly used for high-voltage transformers (shown in Fig. 11) and outdoor circuit breaker panels.
- Ex q protection method encapsulates electrical components in sand or other powder. The letter “q” refers to quarts, but glass balls and silica pearls can also be used. This design principle is often used for weighing sensors, lighting fixtures, phones, and visual displays.



Fig. 11. Ex m (left), ex o (middle), and ex q (right)

12.7.7 Ex t (protection by enclosure, dust only)

Ex t is the protection code for protection by enclosure and is one of the few protection codes exclusive to electrical equipment installed in a dusty environment. At first glance, it may seem like a variant of Ex d (explosion-proof enclosure); however, Ex t does not rely on flame paths.

However, the primary design principle of ex t is to provide a dust-tight enclosure that prevents ingress and reduces the likelihood of internal ignition or explosion if dust does intrude. The protection has three sub-categories: Ex ta, Ex tb, and Ex tc, with characteristics summarized and compared in Tab. 11.

Tab. 11 Summary of characteristics for Ex t categories

Characteristic	Ex ta	Ex tb	Ex tc
Equipment protection level (EPL)	Da	Db	Dc
Zone suitability	Zone 20	Zone 21	Zone 22
Ingress protection (IP)	IP6X (dust-tight)	IP6X (dust-tight)	IP5X (dust protected) or IP6X (dust-tight)
Surface temperature limits	Most stringent; internal & external testing	External testing; less strict internally	External only; normal operation
Internal temperature measurement	Required	Not required to the same extent	Not required
Arcing/sparking parts	Strongly restricted	Allowed with conditions	Generally avoided but not prohibited
Fault tolerance	Not losing protection in case of one fault, even against exceptional faults	Not losing protection in case of one foreseeable fault	Expected to maintain protection under normal operation only, and after fault, the protection may be lost

In addition to the enclosure, cable entries and junction boxes located in the same zone must also be certified as Ex ta, Ex tb, or Ex tc, as needed, based on the applicable zone in which the equipment is installed. It is not possible to use Ex e junction box in combination with Ex t to simplify cable entries, as is done for Ex d.

12.8 Comparison of codes

A comparison of some of the ATEX and EN IEC 60079 codes is done in Tab. 12. For example, ATEX code 1 G means the equipment can be used in zone 0 in atmospheres containing explosive gases. The corresponding IEC 60079 code specifies that such equipment must withstand two faults without losing Ex-protection. According to IEC 60079, Ex equipment with protection codes Ex ia, Ex o, and Ex s can be used in such areas.

Tab. 12. Alignment of ATEX and IEC 60079 equipment coding

Zone	Ex protection code (IEC 60079)	Equipment protection level (EPL) (IEC 60079)	Equipment + environment categories (ATEX)
0	Ex ia, Ex o, Ex s	Ga	1 G
1	As for zone 0 or Ex ib, d, e, m, p, o, q, m, s	Gb	2 G
2	As for zone 0 or 1, or Ex n	Gc	3 G
20	As for zone 0*	Da	1 D
21	As for zone 1*	Db	2 D
22	As for zone 2*	Dc	3 D

*There are some differences between the protection codes applied for explosive atmospheres and dust, and they are summarized in Tab. 13.

Tab. 13. Ex-protection codes for flammable gas vs dust environments

Protection Principle	Gas Environment Code(s)	Dust Environment Code(s)	Same protection applied?
Flameproof (gas)/ Protection by enclosure (dust)	Ex d	Ex t (Ex ta / Ex tb / Ex tc)	No
Increased Safety	Ex e	(none – no ex e equivalent for dust)	No
Intrinsic Safety	Ex ia / Ex ib / Ex ic	Ex ia / Ex ib / Ex ic	Yes
Pressurization	Ex p (px / py / pz)	Ex p	Yes
Encapsulation	Ex ma / Ex mb / Ex mc	Ex ma / Ex mb / Ex mc	Yes
Non-sparking	Ex n (nA / nC / nR)	(not used for dust) – see ex t	No
Protection by Enclosure (current)	(none)	Ex t (Ex ta / Ex tb / Ex tc)	No
Protection by Enclosure (legacy)	(none)	Ex tD (legacy EN/IEC 61241-1)	No (historical only)

12.9 Labeling of Ex equipment

The EU Equipment Directive requires that Ex equipment is labeled with ATEX and IEC 60079 Ex coding. The label is fastened onto the equipment, like the example shown in Fig. 12.



Fig. 12. Labels mounted onto equipment (Rosemount and Pepperl+Fuchs)

The information provided with the label may look like the one in Fig. 13.

We recognize that the information is grouped into sections:

- ATEX coding and information:
 - Left side:
 - The CE letters plus the unique identification code for the notified body registered in the EU New Approach Notified and Designated Organization (NANDO) database. The role of the notified body is to monitor that the manufacturing process consistently produces equipment that conforms to the type-approval made earlier
 - The current year of the manufacturer of the equipment
 - Right side:

- The short name of the notified body that made the original (and still prevailing) assessment of the Ex-design against the ATEX directives
- The initial certification year (still applicable to the equipment)
- The certification number
- IEC 60079 equipment coding (middle), corresponding to similar information as for ATEX coding.

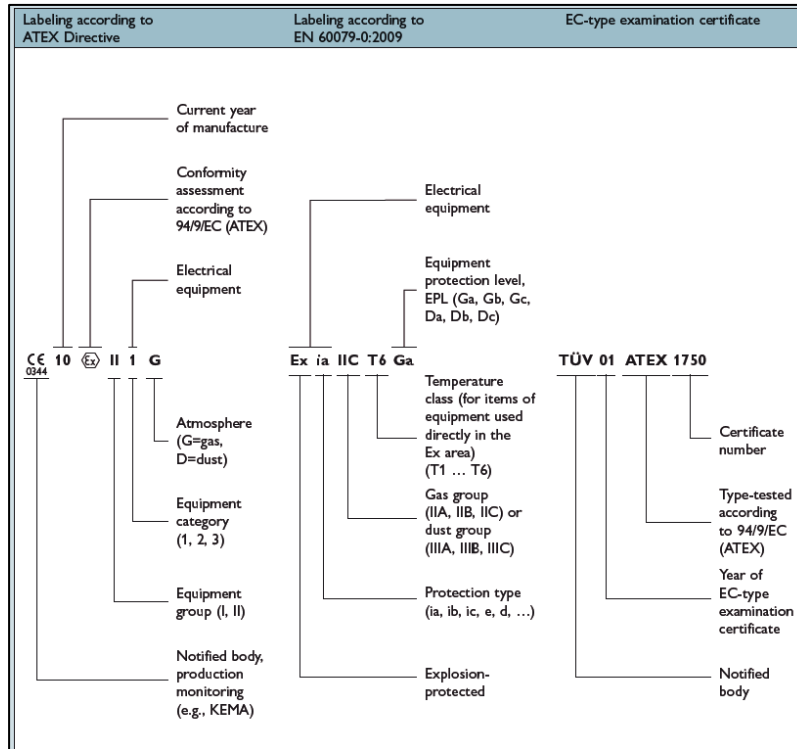


Fig. 13. Ex labeling Example 1 (originally made by Phoenix Contacts)

The information that can be extracted from Fig. 13 is:

- The equipment was produced in 2010, and the notified body DEKRA Certification B.V. assessed the production process.
- The equipment type was already certified against ATEX in 2001 by TÜV
- The equipment can be used in areas with explosive gas atmospheres in Zone 1 if it is not in mines
- The equipment tolerates two faults and has an Ex-protection code, Ex ia, meaning it is intrinsically safe
- The equipment can have a surface temperature of up to 86 degrees (T6)
- The gases must have lower ignition energy than 20 μ J and can be used for hydrogen and acetylene.

Another example of an Ex-label is shown in Fig. 14. Here, we can extract that:

- Can be installed in areas classified as Ex-zone 1, but not in mines
- The gases must have a lower ignition energy than 20 μ J, such as those in atmospheres with hydrogen and acetylene.
- Designed so that the surface temperature is always less than 135 degrees C (T4)
- The equipment can tolerate an explosion inside the housing (Ex d) and has high protection and the ability to resist single faults.

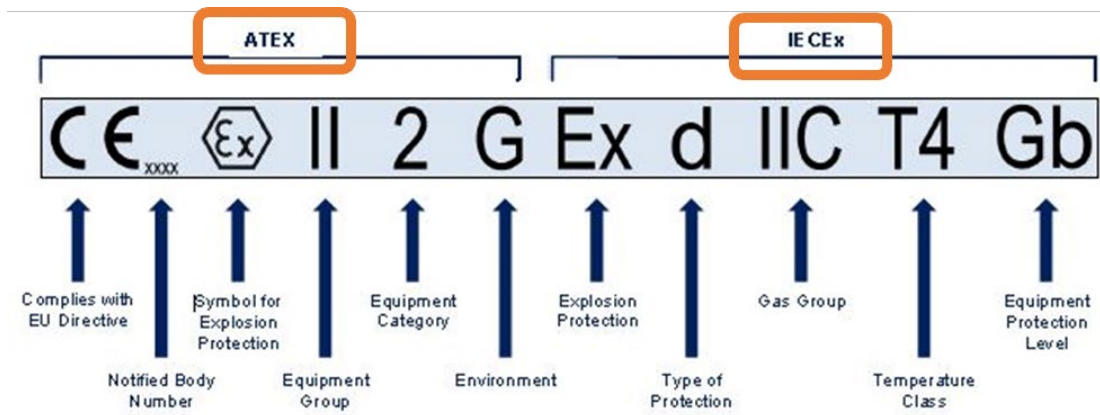


Fig. 14. Ex labeling example 2

12.10 What if additional Ex-protection measures are needed?

Not all equipment can be designed solely in accordance with (EN) IEC 60079. For example, there may be explosion risks associated with a specific use that the device's existing protection does not address. The standard to use in this case is European EN 50495 (2010) on safety devices required for the safe operation of equipment in the presence of explosion risks. Examples where this standard applies are:

- Pressurization protection implemented with other or additional principles than what IEC 60079 specifies for Ex p
- Extra overload protection device added to an electrical motor of type Ex e
- Control devices for battery charging equipment to protect against overcharging or deep discharging
- Level detectors for controlling submersible pumps installed in Ex-zone 0, to ensure the pumps are isolated from explosive atmospheres.

EN 50495 applies functional safety principles to the implementation of additional Ex protection measures, utilizing safety integrity levels (SILs) up to SIL 2. The explanation in EN 50495 of requirements to SIL 1 and SIL 2 implementations is a bit cumbersome to read, and an interpretation is provided in Tab. 14. After selecting components, the reliability must be calculated and compared with the specified SIL range. The choice of reliability measure depends on the mode of operation of the safety measure, i.e., probability of failure on demand (PFD) for Ex protection measures operating in the on-demand mode and probability of having a dangerous failure per hour (or dangerous failure frequency) for measures operating in the high/continuous demand mode.

Tab. 14. EN 50495 requirements for additional Ex safety protection measures

Equipment group	Zone	Equipment category	SIL requirement	Minimum hardware fault tolerance (HFT)
Mine (I)	Not used. Must prevent any ignition source	M2: Tolerate two faults	2	1
		M1: Tolerate single fault	1	0
Other than mines - gases (II) – IIA, IIB, IIC	0	Tolerate two faults	2	1
	1	Tolerate single fault	1	0
	2	General robustness	--	--
Other than mines - dust (III)	Same as for II	Same as for II	Same as for II	Same as for II

12.11 Bibliography

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