Wuhan University of Technology

Blasting Engineering

Chapter 1 Basic theory of Explosion

Contents

本章思考题

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Contents

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1.1 Some basic concepts

A chemical substance or mixture has a explosive effect , or undergoes a rapid chemical reaction with great energy release, gas production on certain conditions

Explosive

Classification of explosion:

- **Physical explosion**（**without chemical reaction**）
- **Nuclear explosion**（**nuclear fission or nuclear fusion**）
- **Chemical explosion**（**new substance generated**）

The three factors of chemical explosion

1

Exothermic reaction

The required energy by explosion

2

A high-speed reaction

The important symbol of explosion reaction different from a normal chemical reaction

3

Lots of gas production generated in reaction

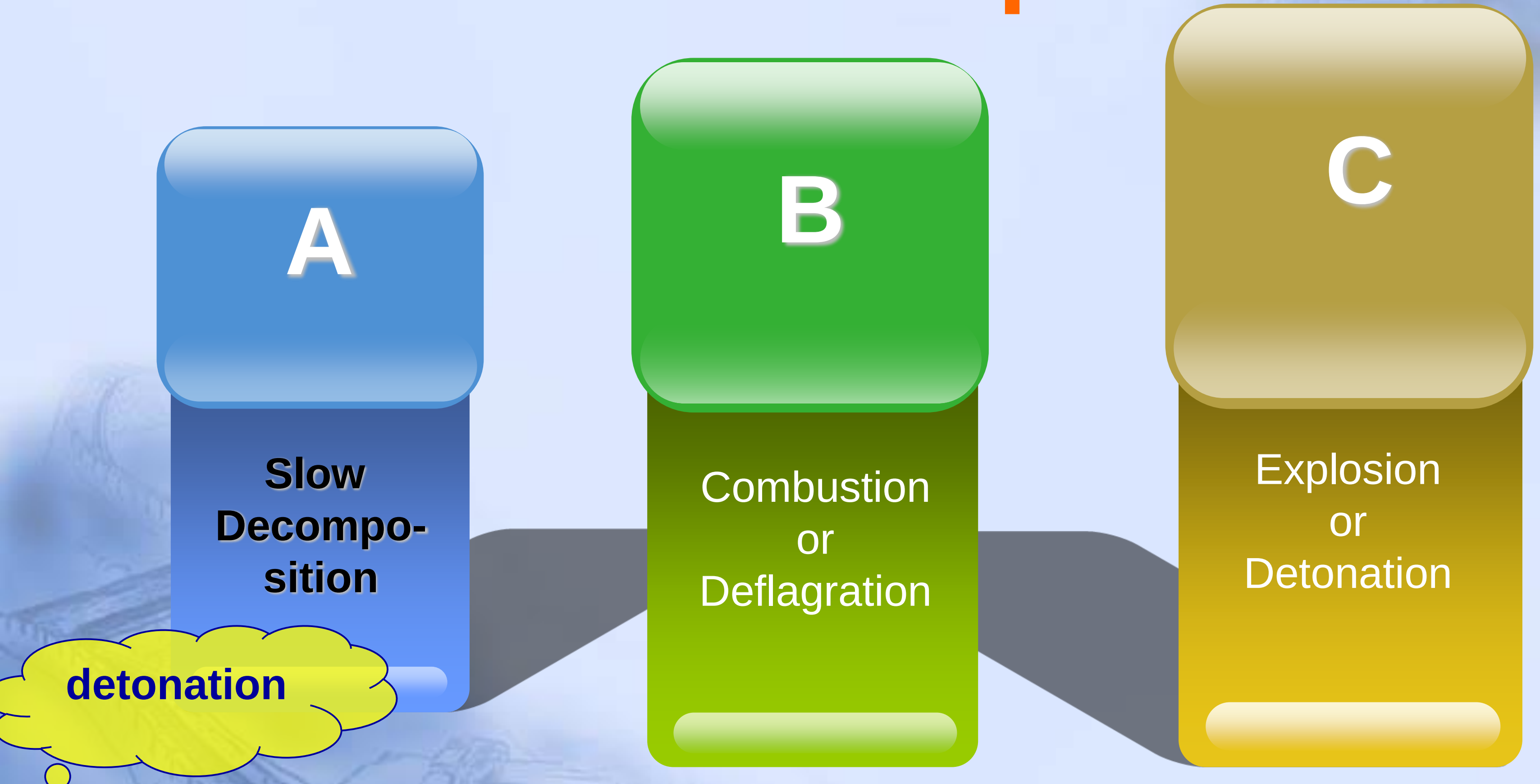
The medium of explosion working outside

★ Aluminothermic Reaction ★

- $2Al+Fe_2O_3 \rightarrow Al_2O_3+2Fe+828kJ$

- This process reacts sharply, and releases lots heats that the temperature of productions can be heated to 3000K.
- However, no gas is generated in this process, so the reaction can not work outside because of the lack of the medium which change the heat energy to the mechanic energy.
- Therefore, the reaction is not a explosion case.

1.2 Basic forms of chemical reaction of explosives



An explosion whose reaction rate reaches the maximum stationary detonation velocity, which could be thousands m/s.

1.3 the oxygen balance and the reaction production

Oxygen balance

The oxygen balance means the difference between the oxygen content in the explosive and that requierd oxygen, which can oxidize all the combustible elements.

The oxygen balance is usually expressed by the mass (gram) or the mass fraction of the oxygen difference (redundance or lack) in per gram explosive.

Calculation of oxygen balance

The general formula of explosive can be expressed as:

$$C_aH_bN_cO_d$$

so, the oxygen balance can be calculated by:

$$Q_b = \frac{1}{M}\left[d - (2a + b/2)\right] \times 16 \times 100\%$$

where

Q_b —— The oxygen balance of explosive;

M —— The molar mass of explosive（g/mol）;

16 —— The molar mass of oxygen （g/mol）

Calculation of oxygen balance of the explosive mixture

the calculaiton formula：

$$Q_b = \frac{1}{1000}\left[d - (2a + b/2)\right] \times 16 \times 100\%$$

or

$$Q_b = \sum m_i Q_{bi}$$

where m_i Q_{bi} **are the mass fraction and the oxygen balance of conponent *i*, respectively.**

Three forms of oxygen balance

$Q_b>0$	$Q_b=0$	$Q_b<0$
Positive oxygen balance	Zero oxygen balance	negative oxygen balance

Formula calculation of the explosive mixture

- The formulation of explosive mixture which contents tow components:

Supposing x、y are the ratios of the oxidizer agent and the combustible material, respectively, and Q_x、Q_y、Q_b are the oxygen balance values of the two components and their mixture, respectively. so,

$$\begin{cases} x + y = 100\% \\ xQ_x + yQ_y = Q_b \end{cases}$$

For example：

Making up the zero oxygen balance rock explosive **with ammonium nitrate, TNT and wood powder, trying to calculate their values and get a formula.**

Supposing x, y, z are the mass fractions of ammonium nitrate, TNT and wood powder, respectively. Their oxygen balances can be obtained by checking table, and the oxygen balance of ammonium nitrate is 20%, TNT 74%, and wood powder 138%. Therefore, the following can be deduced by the zero oxygen balance:

$$\begin{cases} x+y+z=100\% \\ 0.2x-0.74y-1.38z=0 \end{cases}$$

If $y=0$， then $\begin{cases} x=87.34\% \\ z=12.66\% \end{cases}$

If $z=0$， then $\begin{cases} x=78.72\% \\ y=21.28\% \end{cases}$

their values range of the three components are: **ammonium nitrate** $x=78.72\sim87.34\%$,TNT $y=0\sim21.28\%$,and wood powder $z=0\sim12.66\%$

If TNT y=10%， then $\begin{matrix} x=83.3\% \\ z=6.7\% \end{matrix}$

Products and toxic gases of detonation

- （1）products of detonation：

  The chemical reaction production in the reaction zone at the end time of explosive detonation reaction. It is the basis for calculation of the thermal effects of detonation

- （2）products of explosive：

  The detonation production expands furthermore, or interacts with other matters (the ambient air, rock and so on). The new reaction would generate new products, called products of explosive.

- （3）toxic gases：

  CO 、 H_2S、 SO_2和NOx

  To calculate the sum of toxic gases, the other toxic gases should be convert to CO, and the conversion coefficient of Nox is 6.5, and SO2, H2S 2.5.

Main factors of toxic gas products

A Explosive oxygen balance

B Degree of chemical reaction

C The waxed paper enclosure of explosive

D The rock contents sulfur

It produces some toxic gases, such as H_2S、SO_2

4 Thermochemical parameters of explosive

Specific volume of blasting

The volume of gas products under the standard state by the explosion per kilogram explosive(unit: L/kg)。 The large specific volume means the large working capacity of explosive.

Explosion heat

The released heat by the explosion per kilogram explosive (unit: J/kg or kJ/kg). The solid explosive changes into gas products in the explosion instant, and the products don't expand until the end of explosion. Therefore, the explosion can be considered to a constant volume process.

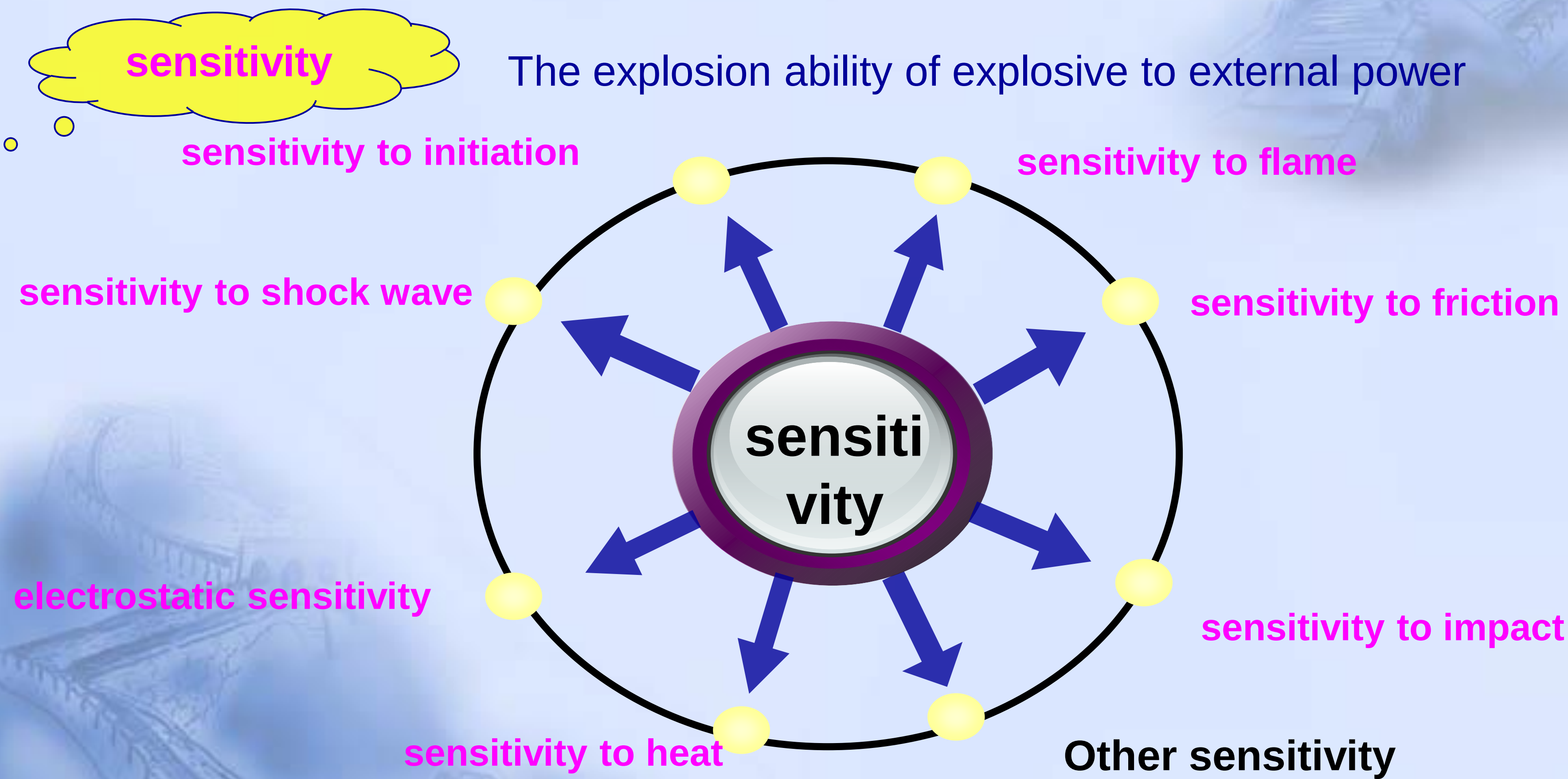
Explosion temperature

The maximum temperature of explosion products reach because of the explosion energy

Explosion pressure

The fluid static pressure value when the explosion products reach their thermal balance in the initial volume after the explosion. Explosion pressure is also defined as the instant pressure on the wall of borehole at the explosion end time of explosive, so it is also called as borehole pressure.

5 Explosive Sensitivity



The explosive sensitivities varies to the different external power forms. Therefore, it is not reasonable to measure its sensitivity to certain initiation power with one to another initiation power.

Sensitivity to Heat and Mechanical Sensitivity

Sensitivit-y to heat

means the explosive ability to heat

sensitivity to heat is usually expressed by the ignition point.

the heat mainly includes two ways： the uniform heating and the pilot of flame.

Mechanical Sensitivity

（1）sensitivity to impact — the explosive ability to impact

（2）sensitivity to friction — the explosive ability to friction

Explosive sensitivity to initiation

sensitivity to initiation

explosive sensitivity to initiation means the detonation ability of high explosive to the explosion of other explosive (primary explosive, primer and so on).

The explosive with **cap sensitivity** means that can be initiated reliably**by No. 8 blasting cap in one time.**

The explosive with **cap insensitivity** means that cannot be initiated reliably**by No. 8 blasting cap in one time.**

Sympathetic Detonation of Explosive

sympathetic detonation

Sympathetic detonation means the phenomenon that the explosion of explosive (donor cartridge) induces the explosion of adjacent explosive (receptor charge) .

transmission distance

Transmission distance means the maximum distance between the two charges that the donor cartridge can initiate the receptor charge 100%.

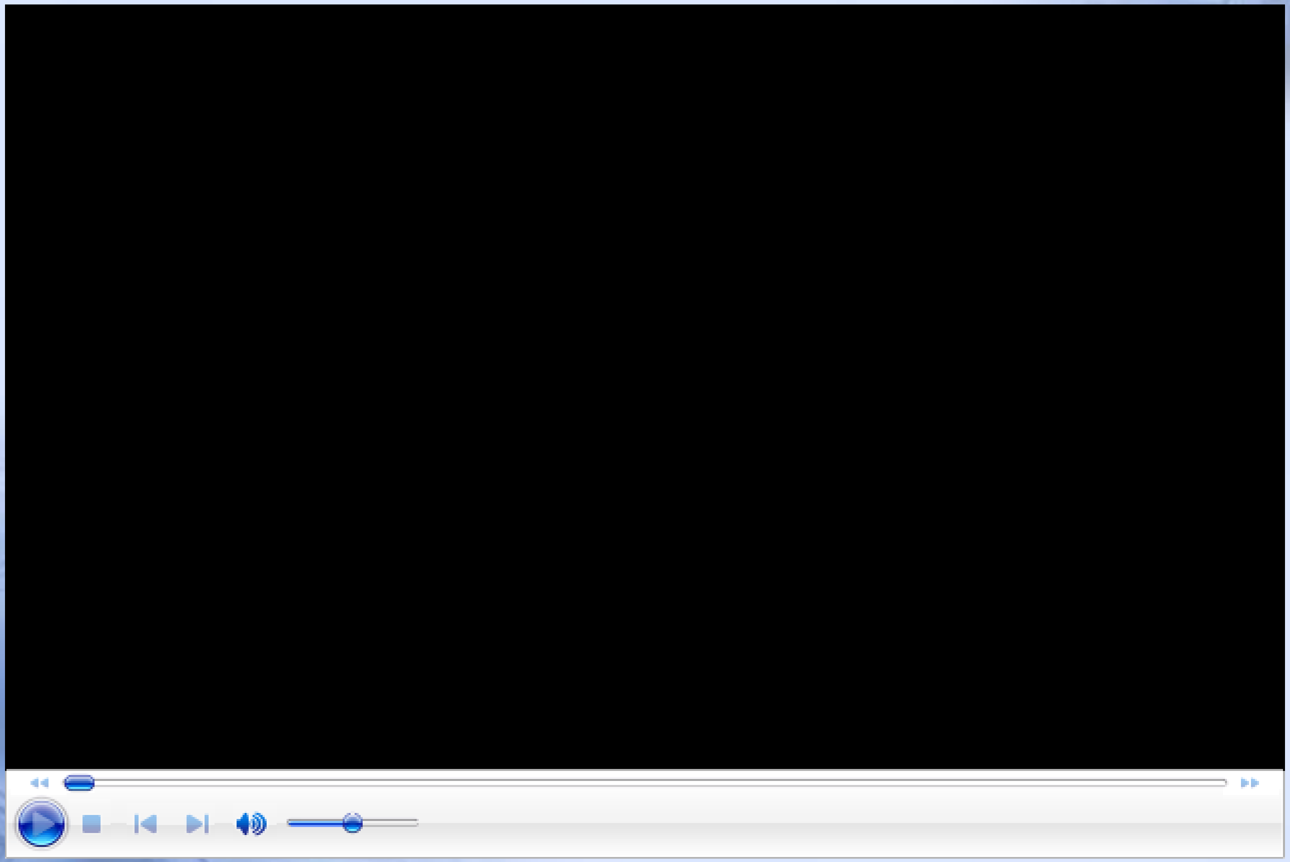
The flash-over capability of explosive is expressed by the transmission distance, and the unit is cm.

Objective of studying Sympathetic Detonation

(1) For determining the safety distance among the production rooms, and supplying basic data for workshop design;

(2) For improving the properties of industrial explosive, and the reliability of initiation or transmission in engineering blasting.

Measurement of Transmission Distance



Factors of Transmission Distance

A — Charge concent-ration

B — Dose and diameter of charge

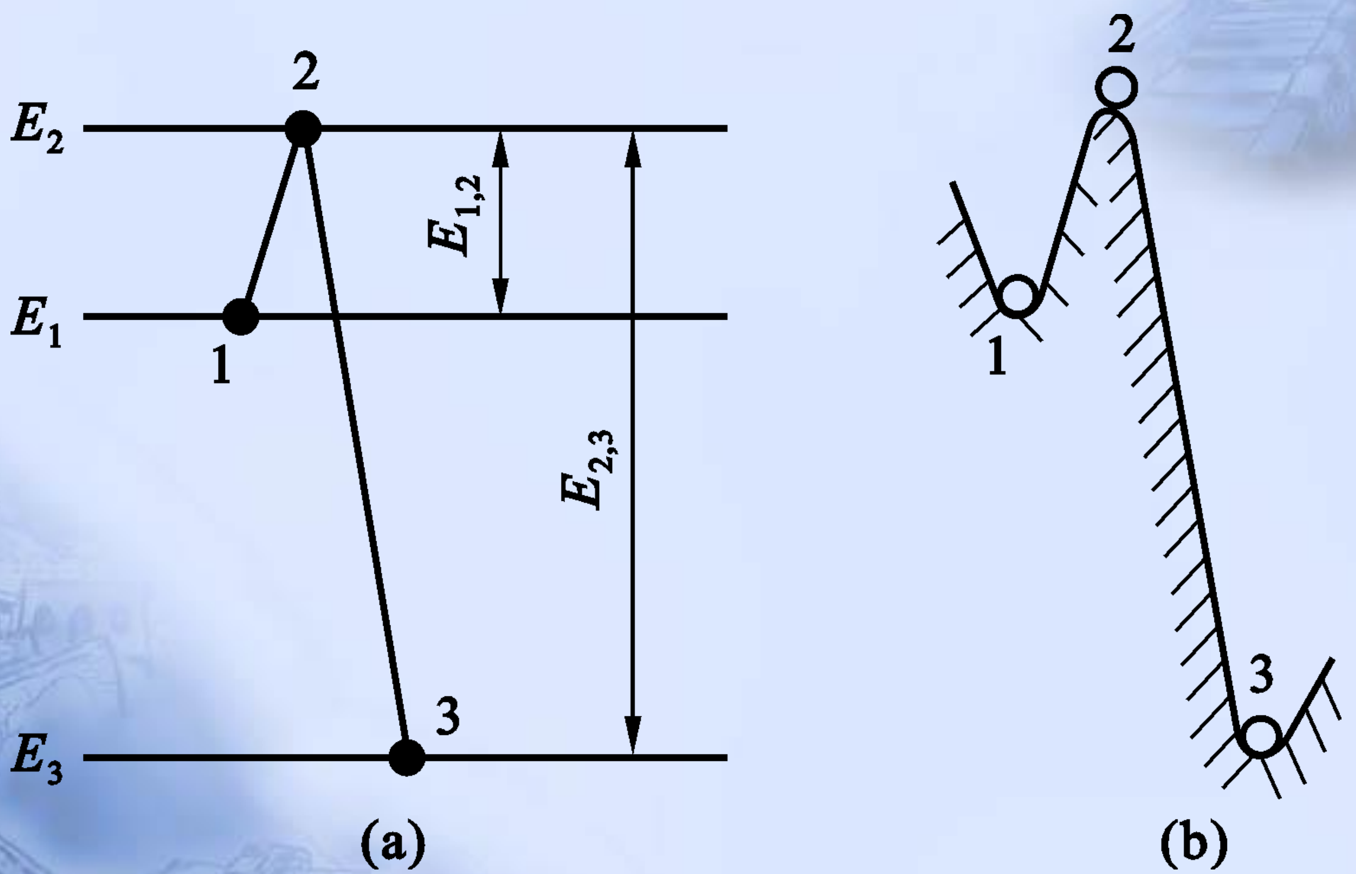
C — Shell and connection mode of charge

Factors of explosive sensitivity

Factors

1. Temperature of explosive
2. Physical state and crystal morphology of explosive
3. Particle size of explosive
4. Charge concentration
5. appendage

6 Initiation of Explosive



炸药爆炸的能栅图

Hotspot Initiation Theory

Hotspot initiation theory

Hot spot initiation theory also known as hotspot theory

Hotspot theory： With the mechanical effect , Most of mechanical energy of explosive is converted into heat energy firstly. The mechanical effect is not uniform, so heat energy affects a local explosive rather than the whole, and form a hotspot. The explosive around the hotspot undergo thermal decomposition firstly and release heat meanwhile. The released heat prompt the sharp rise of decomposition rate of the explosives . If the number of hotspots in explosive is enough and their size are large enough, explosives around these hotspots will be excited and then explosion occurs when the hot spot temperature rise to the flashpoint temperature, which finally caused the explosion of part of explosives and even the whole.

Reasons for the formation of the hot spots:

- (1)The air gap or small bubbles inside the explosives is compressed adiabatically with the mechanical effect .
- (2)With the friction effect, the local heating occurred in explosives particles and between explosives and impurities , as well as the container inner wall.
- (3)Hotspot generates due to the viscous flow of explosives.

7 Detonation Theory

Wave

The propagation of disturbance in medium is called wave.

The state parameters of matters change under external actions, and the change of local state is called disturbance.

compression wave

Compression wave means the wave on which the pressure and density both rise due to disturbance.

expansion wave

Expansion wave means the wave on which the pressure and density both decrease due to disturbance.

Formation of Shock Wave

shock wave

Shock wave is a kind of compression wave with a high intensity , which propagates in supersonic speed in medium, and whose pressure rise sharply and then drops gently.

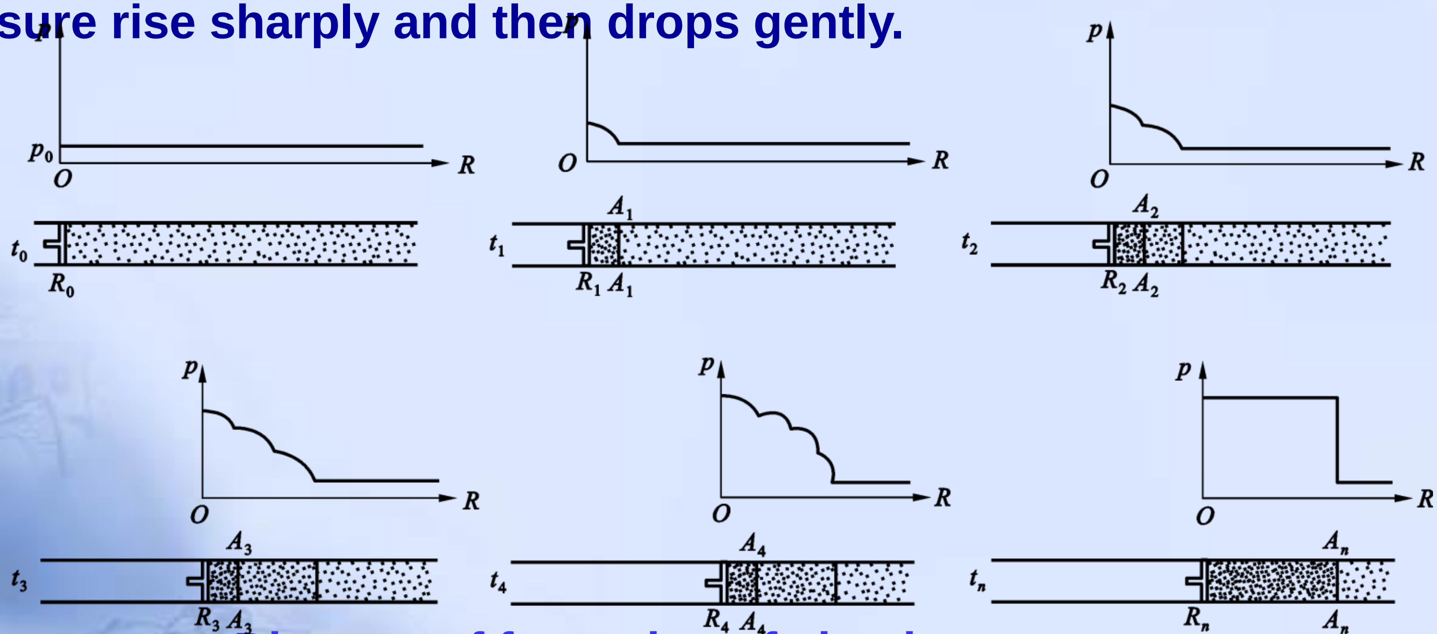


Diagram of formation of shock wave

R—interface between piston and gas A—instant wave front； P—Air pressure in duct

Basic Equation of Shock Wave

$$c = V_0 \sqrt{\frac{P_1 - P_0}{V_0 - V_1}}$$

$$u_1 = \sqrt{(P_1 - P_0)(V_0 - V_1)}$$

$$\frac{\rho_1}{\rho_0} = \frac{P_1(K+1) + P_0(K-1)}{P_0(K+1) + P_1(K-1)}$$

$$c_n = \sqrt{KP_1V_1}$$

Shock Wave Characteristics

1）The velocity of the shock wave is supersonic relative to the unperturbed medium.

2）The velocity of the shock wave is subsonic relative to the medium behind wave.

3） The velocity of the shock wave is related to the intensity of the wave. Due to the erosion of expansion wave and the irreversible energy loss, its strength and the corresponding velocity both decrease with the increasing propagation distance. After it spreads for a certain distance, the shock wave will attenuate into a compression wave and finally a sound wave。

4）The medium state parameters (e.g. speed, pressure, density ,temperature) over the shock wave front change abruptly, so the wave front can be considered as a discontinuity surface where the medium state parameters change discontinuously. Usually A expansion wave follows behind the shock wave.

5）the stationary medium gets a velocity after the shock wave passed by, and the direction is the same as the direction of wave propagation, while its value is less than the wave velocity.

6）The compression of shock wave to the medium is not a isentropic compression. The entropy of the medium increases when the shock wave forms .

7）Shock wave propagation in the way of pulse, which does not have periodicity.

8）When a strong incident shock waves reflects from the surface of the rigid obstacles, the pressure of the reflected shock wave front is 8 times of the one over the incident shock wave front. As the reflected wave has more destructive to the target, we should try our best to avoid possible shock wave reflection when we design the pyrotechnics workshops ,warehouses and so on.

Detonation Wave of Explosive

Detonation wave

The shock wave propagating in explosive with high-rate chemical reaction is called detonation wave.

Detonation velocity

The propagation velocity of detonation wave along charge is called denotation velocity.

Characteristics of shock wave：

① shock wave only exists in the detonation process. Its propagation ends when the detonation ends.

② Detonation wave always have a chemical reaction zone, which is the basis of its steady propagation. In usual, 0-2 zone is called the width of shock wave front, which is about 0.1-1.0 cm，and depending on the explosive type.

③ Detonation wave have steady state, i.e. the parameters on the wave front and its width don’t varies with time until the end of detonation.

Structure of Detonation wave

Wave front

Plane 2-2 is the end face of detonation reaction zone, which is called detonation wave front.

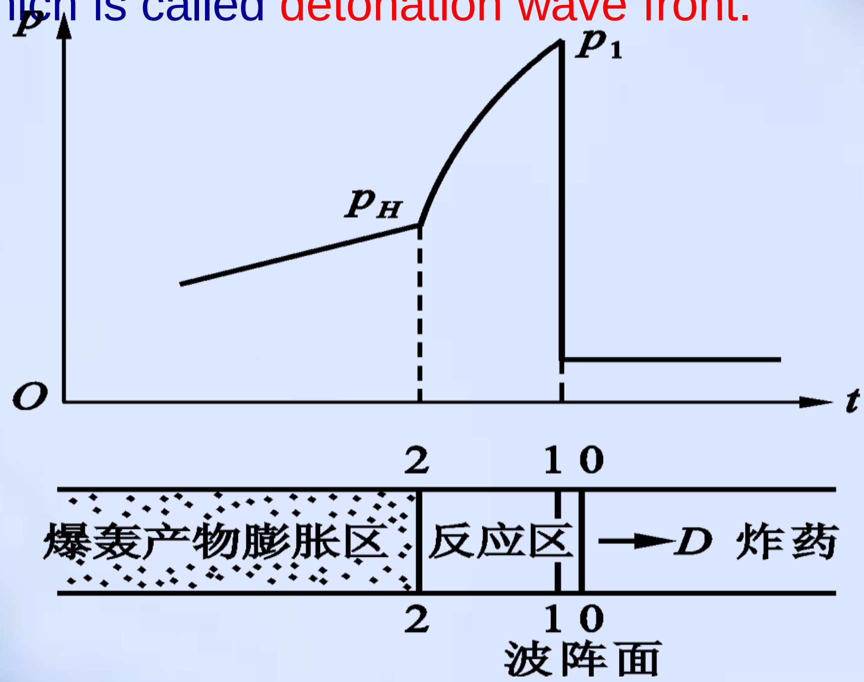


Diagram of detonation wave structure

（Chapaman－Jouguet plane ）

C—J Plane

Usually C-J plane means the ideal detonation wave front under certain Hypothesis.

Parameters of Detonation Wave

Velocity of detonation products on C-J plane ——

Detonation pressure ——

Specific Volume of detonation products on C-J ——

Density of detonation products on C-J ——

Velocity of expansion wave to detonation products on C-J plane ——

$$C_H = \frac{K}{K+1} D$$

Detonation velocity ——

Detonation temperature ——

Detonation Mechanisms of Condensed Explosives

A

Uniform burning mechanism

Uniform burning mechanism also known as the **overall reaction mechanism**

The chemical reaction occurs in the entire detonation wave front simultaneously.

B

Uneven burning mechanism

The temperature of the whole compression layer of explosives rise unevenly, and it burns and generates "ignitor centers" or "hotspots". Furthermore, they reacts firstly, and finally spread to the whole explosives

Three ways

① explosives contained tiny bubbles (gas or vapor) in the adiabatic compression caused by the compression action of the shock wave;

② friction or deformation due to the different speeds of movement between the particle or a thin layer of explosives in the shock wave passed;

③ explosive product gases penetrate into the gap between the explosive particles leaving the surface of the explosive particles heated;

C

Mixed reaction mechanism

Mixed reaction mechanism, also known as **multiple reaction mechanism.** Quadratic-step chemical reaction occurs in the chemical reaction zone

Ideal Detonation and Steady Detonation

Difference

d_l limiting diameter of charge

d_c critical diameter of charge

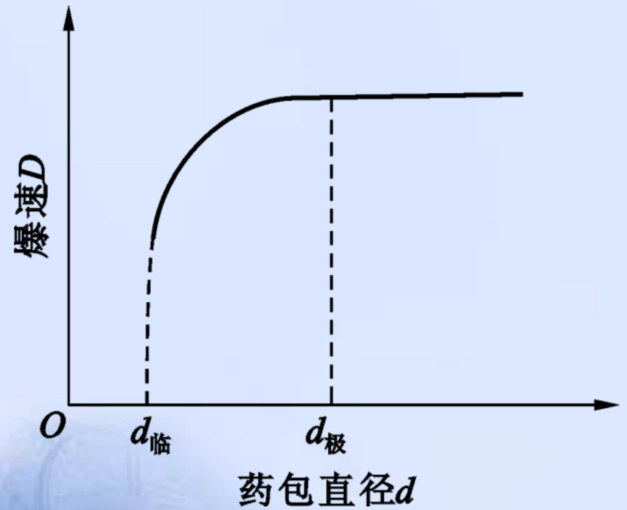
Ideal detonation

If the velocity of detonation remains constant with the increasing of charge diameter and length, such detonation is called ideal detonation.

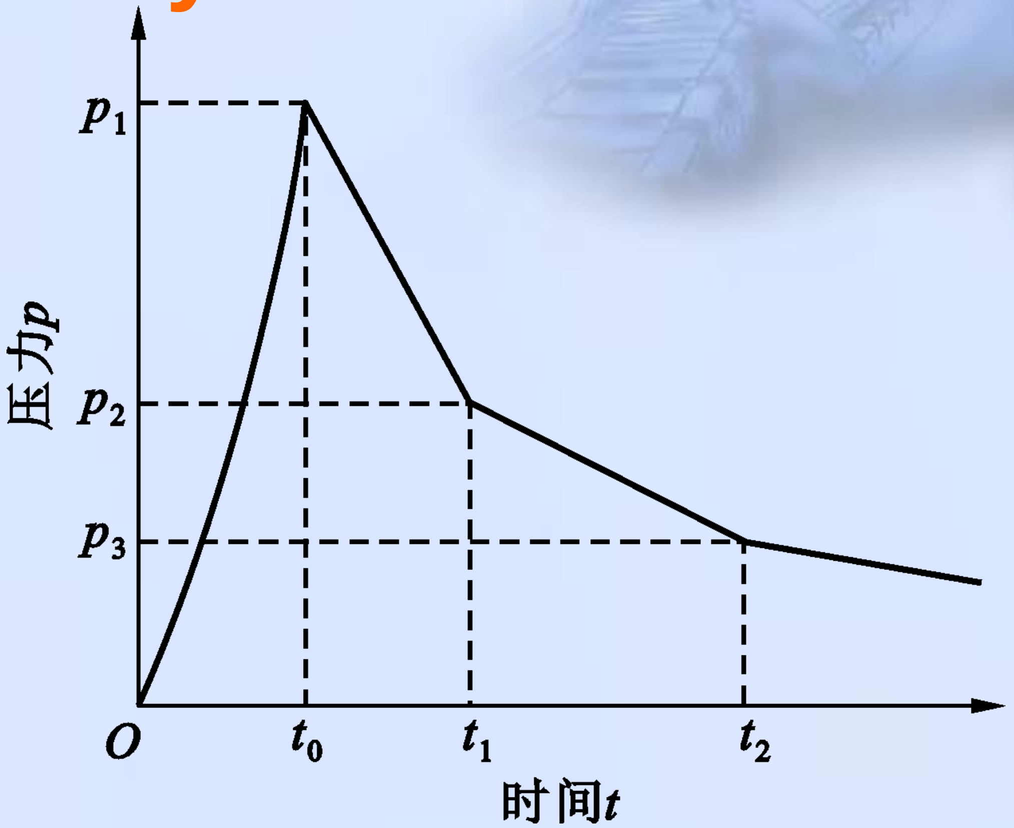
non-ideal detonation

The detonation wave propagating with a lower constant velocity than its maximum detonation velocity is called non-ideal detonation.

Detonation wave pressure and detonation velocity characteristic



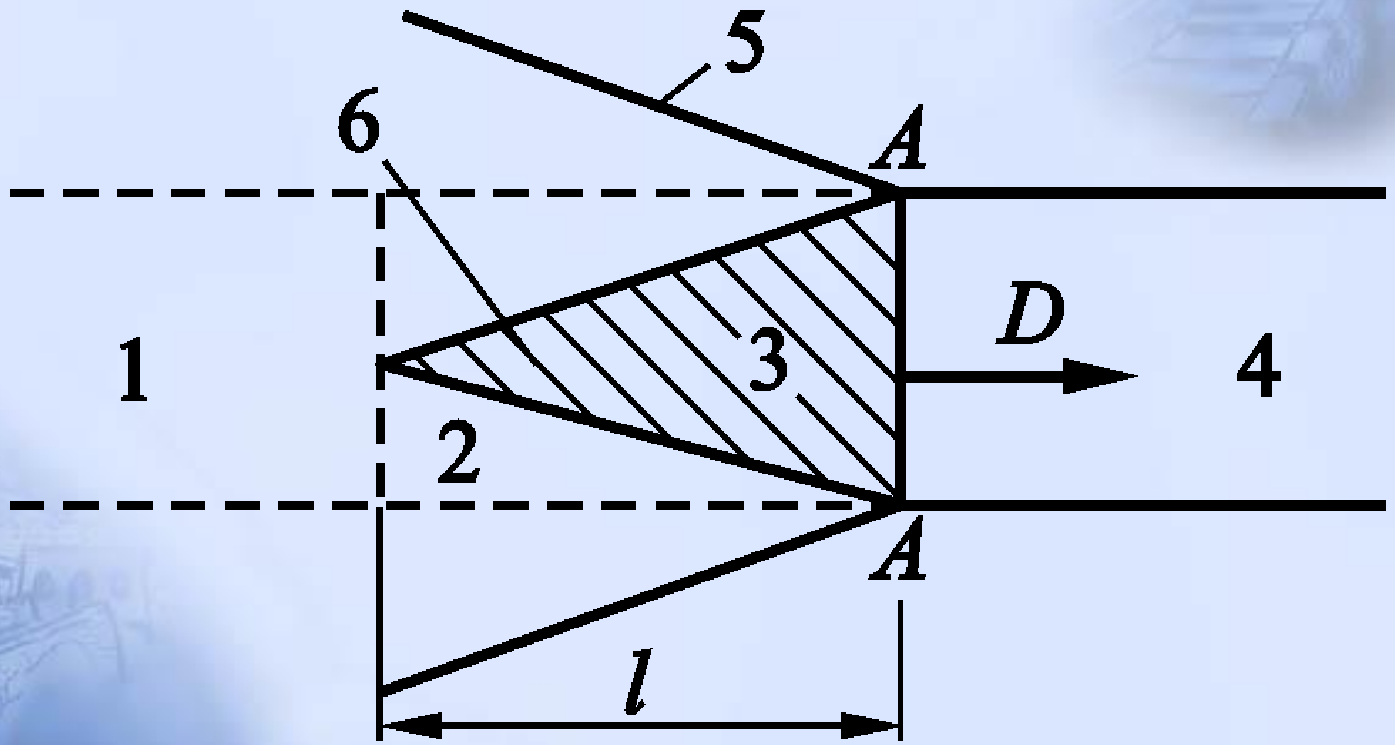
Development of detonation velocity with charge diameter



development of explosive mixture detonation wave pressure with time

t_1—time of the first reaction；t_2—time of the second reaction；t_0—time of compressing explosiv

Influence of lateral diffusion on reaction structure



Influence of lateral diffusion on reaction structure

1—zone of detonation products；2—zone influenced by lateral diffusion；3—effective reaciton zone；4—non-reaction zone（explosive）5—diffusion front；6—expansion front wave；*l*—width of reaction zone；*a-a*—shock wave front

Influence of lateral diffusion with different charge diameters on reaction structure

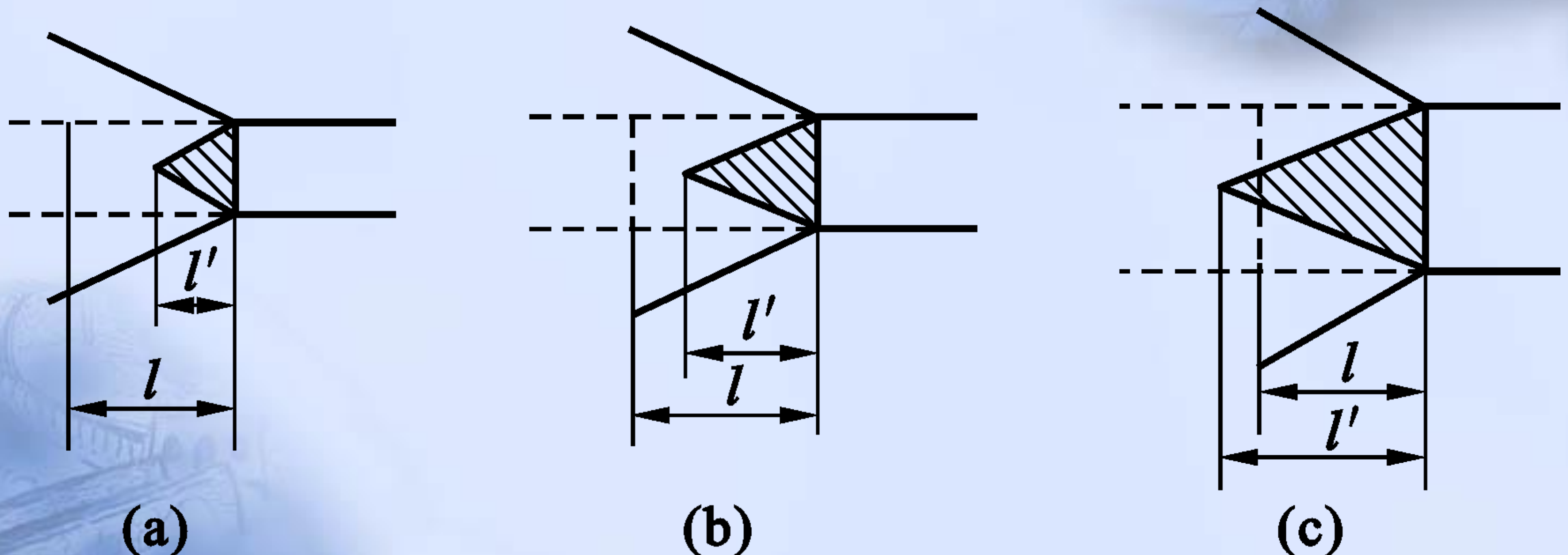


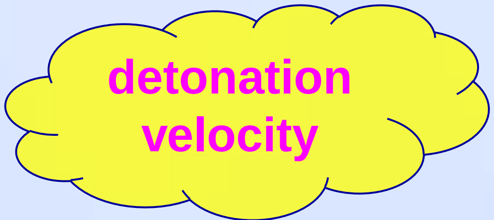
Diagram of lateral diffusion Influence with different charge diameters on reaction structure

l—width of reaction zone *l*‘ —width of effective reaction zone

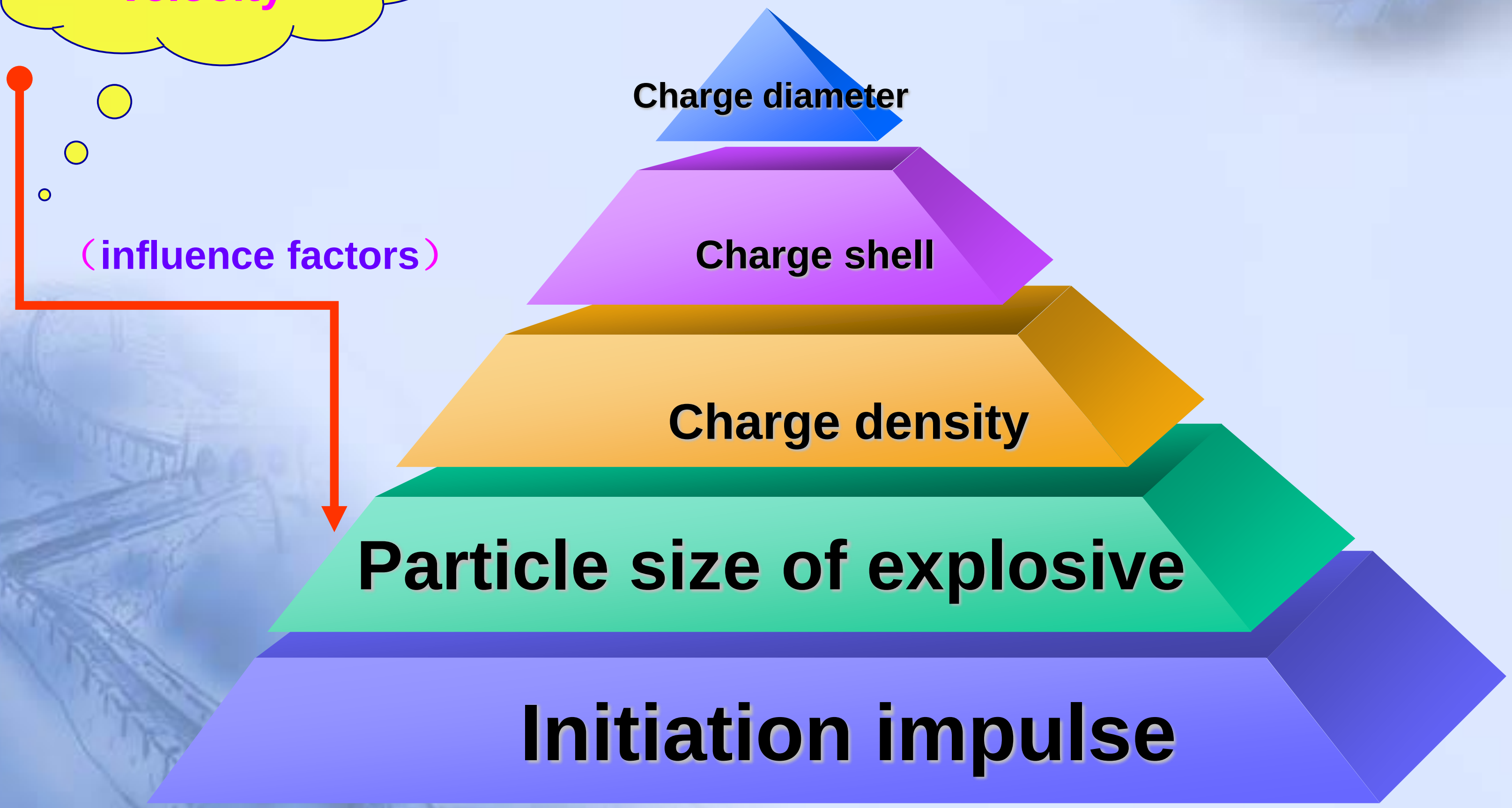
（a） unsteady transmission （b） non-ideal detonation steady transmission

（c） ideal detonation

8 explosive properties

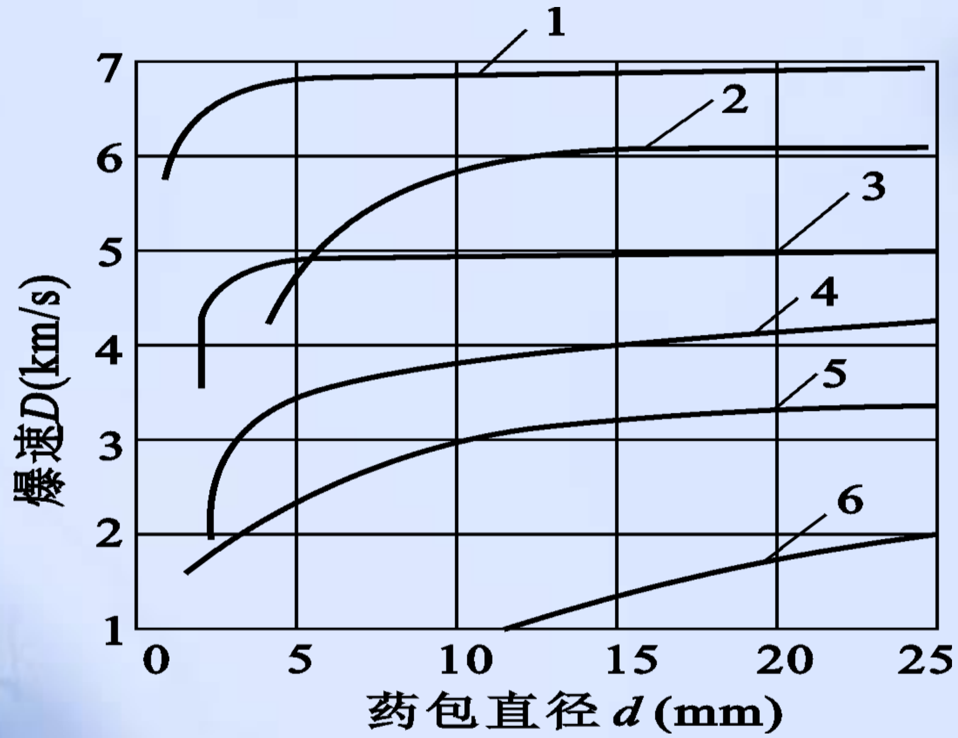


The propagation velocity of detonation wave along charge is called denotation velocity.



$\rho_0 = 1.6g/cm^3$

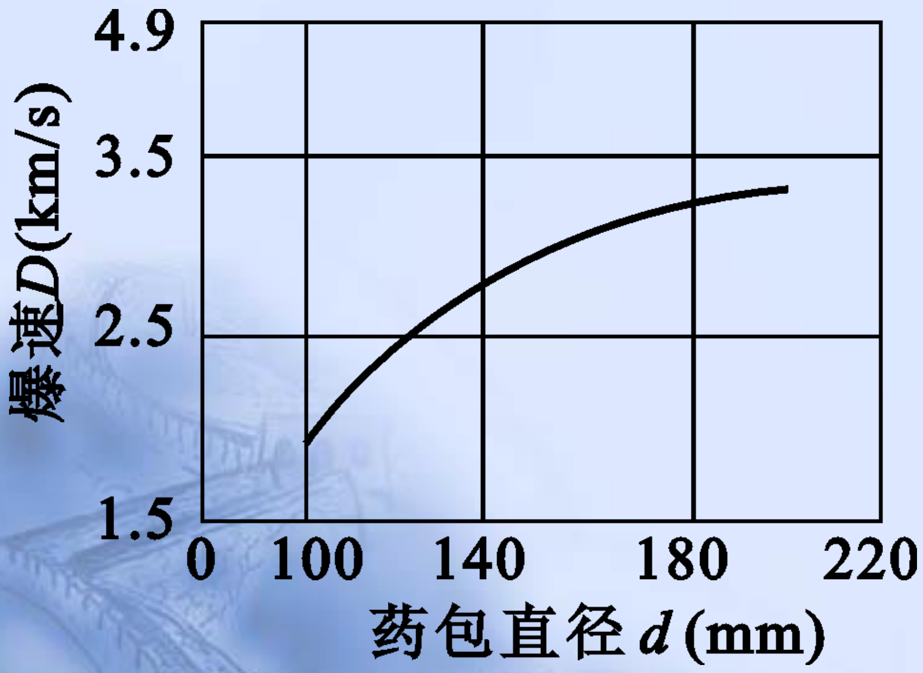
Factors of detonation velocity（1）

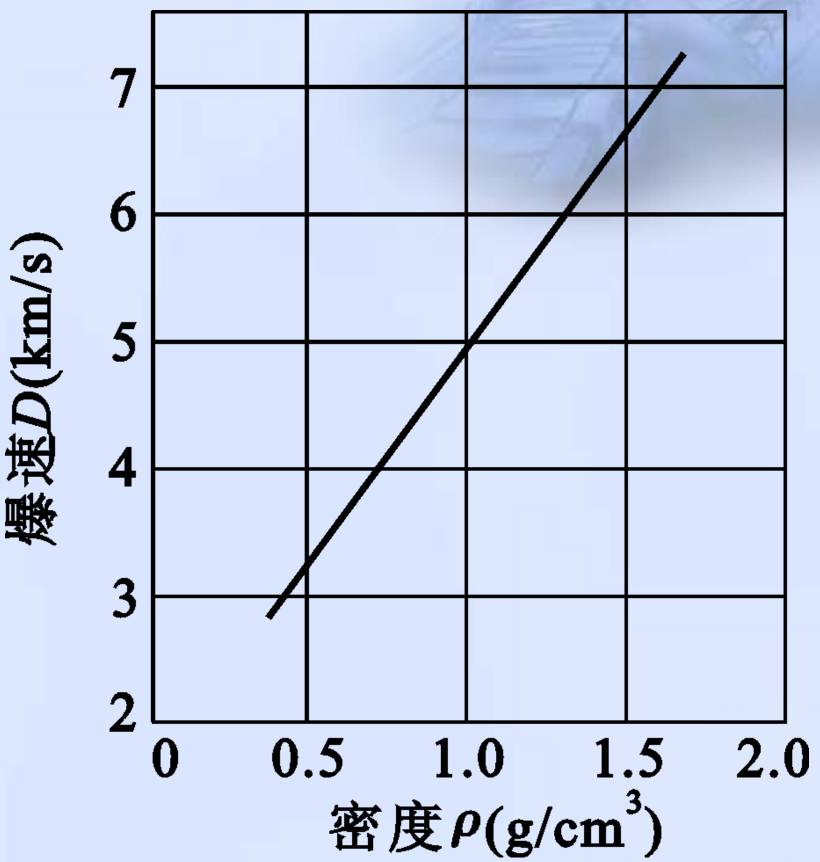


Development of detonation velocity with charge diameter

1—TNT（$\rho_0 = 1.6g/cm^3$）；2—TNT/AN（50/50）（$\rho_0 = 1.53g/cm^3$）；
3—TNT（$\rho_0 = 1.0g/cm^3$）；4—TNT/AN（$\rho_0 = 1.0g/cm^3$）；
5—TNT-NG（$\rho_0 = 0.98g/cm^3$）；6—AN（$\rho_0 = 1.04g/cm^3$）

Factors of detonation velocity（2）

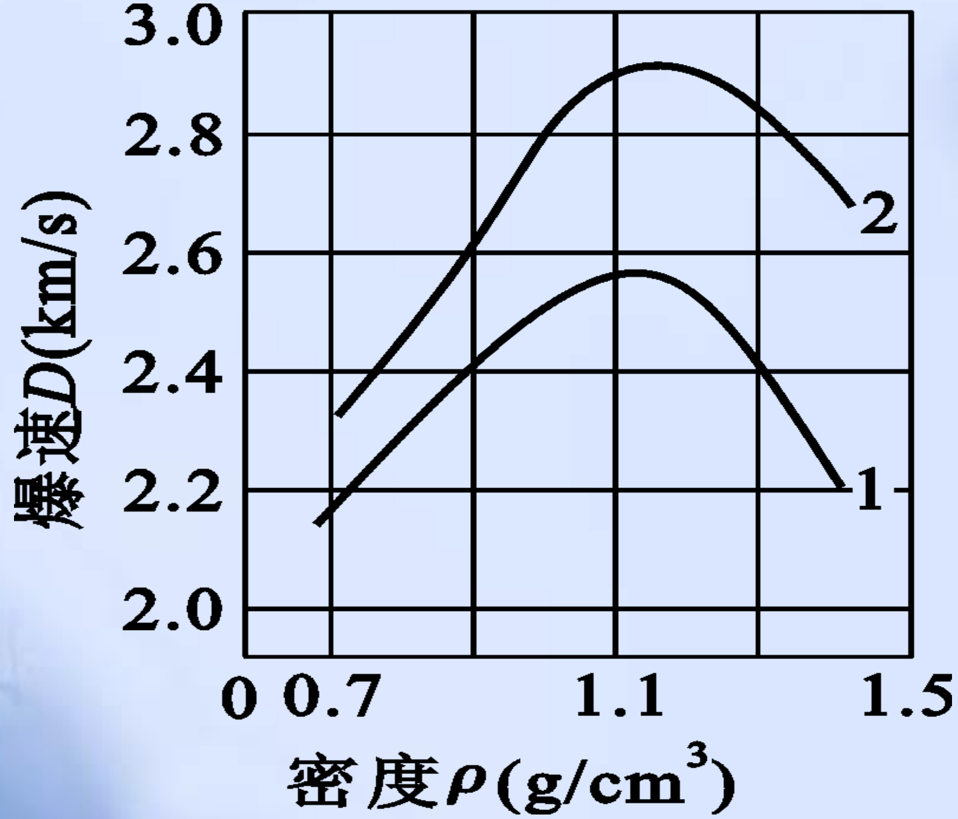




Development of particle-sized ANFO explosive detonation velocity with charge diameter

Influence of TNT charge density on detonation velocity

Factors of detonation velocity（3）



Influence of explosive mixture charge density on detonation velocity

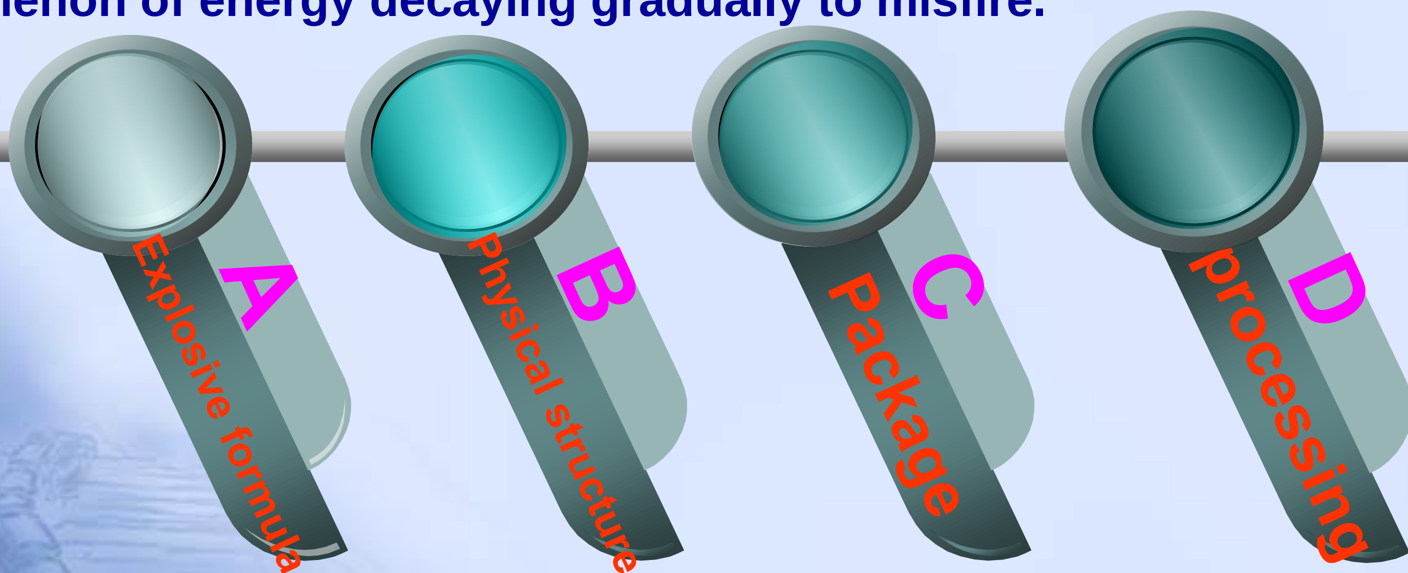
1—charge diameter 20mm； 2—charge diameter 40mm

Pipe effect and its factors

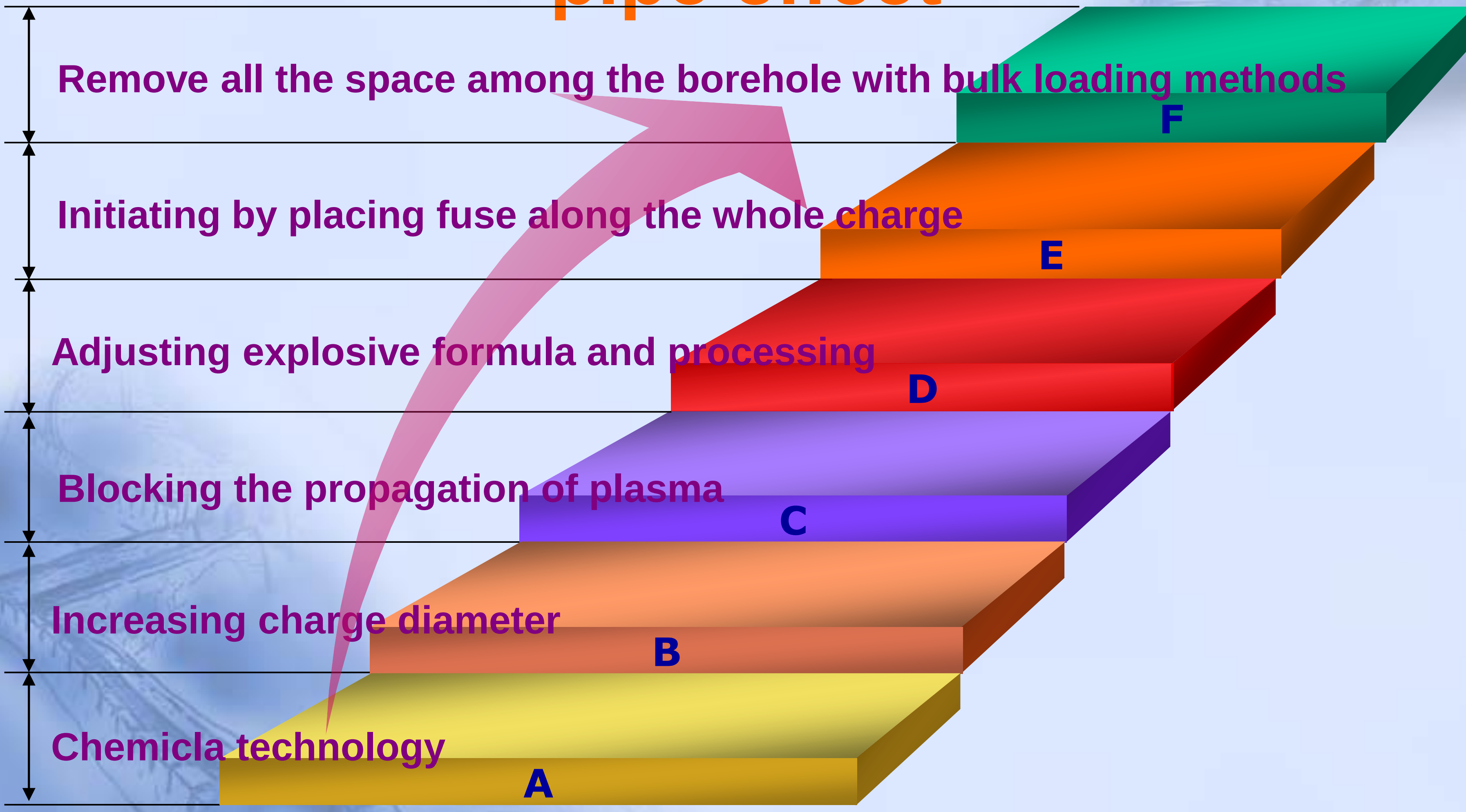
pipe effect

Pipe effect means that the self-restraining of explosive grain caused by the crescent space between cartridge and borehole wall – the phenomenon of energy decaying gradually to misfire.

（Factors）



Measures of decreasing or removing pipe effect

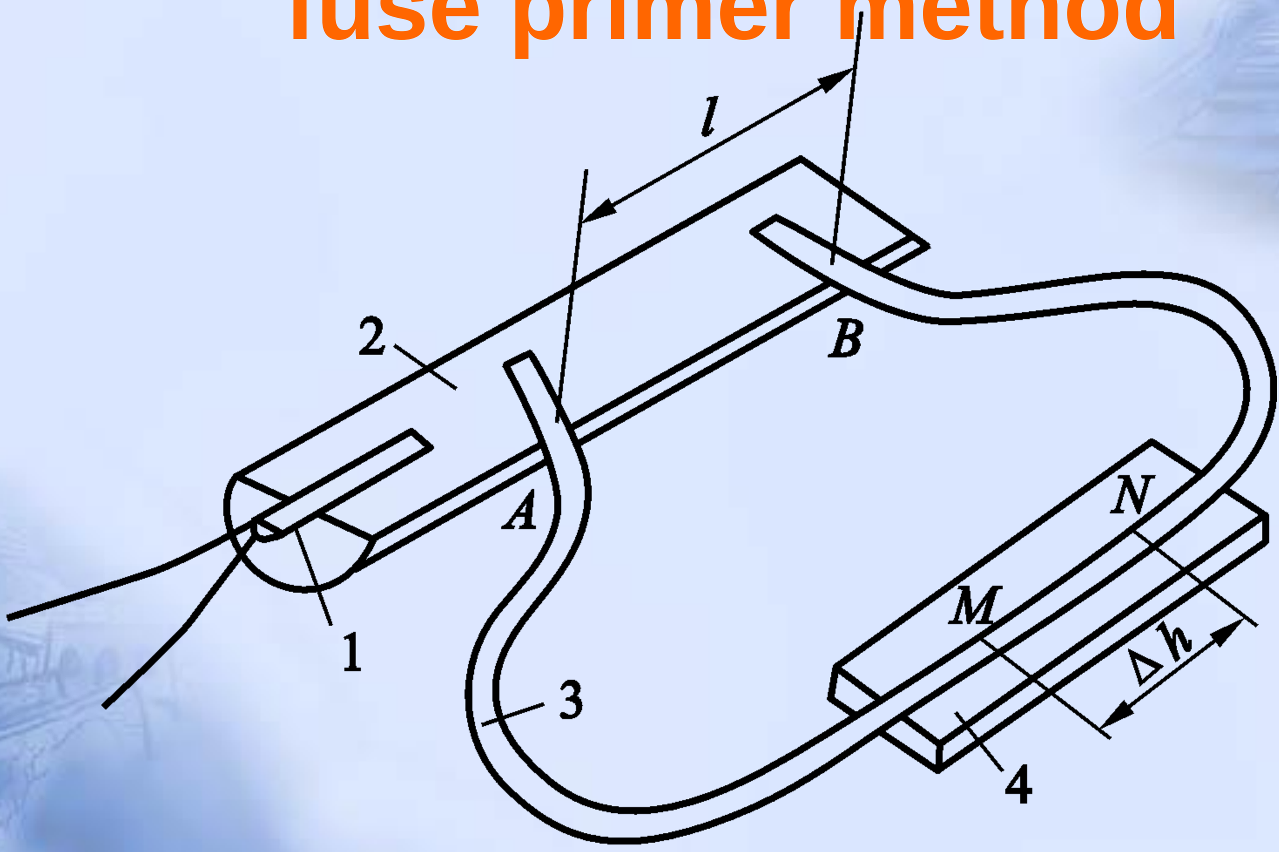


Measurement of detonation velocity

Measurement methods

- Fuse primer method
- electrometric method
  - ①OSC timing method
  - ②Detonation velocity measurement by DTVM
- High-speed photograph method

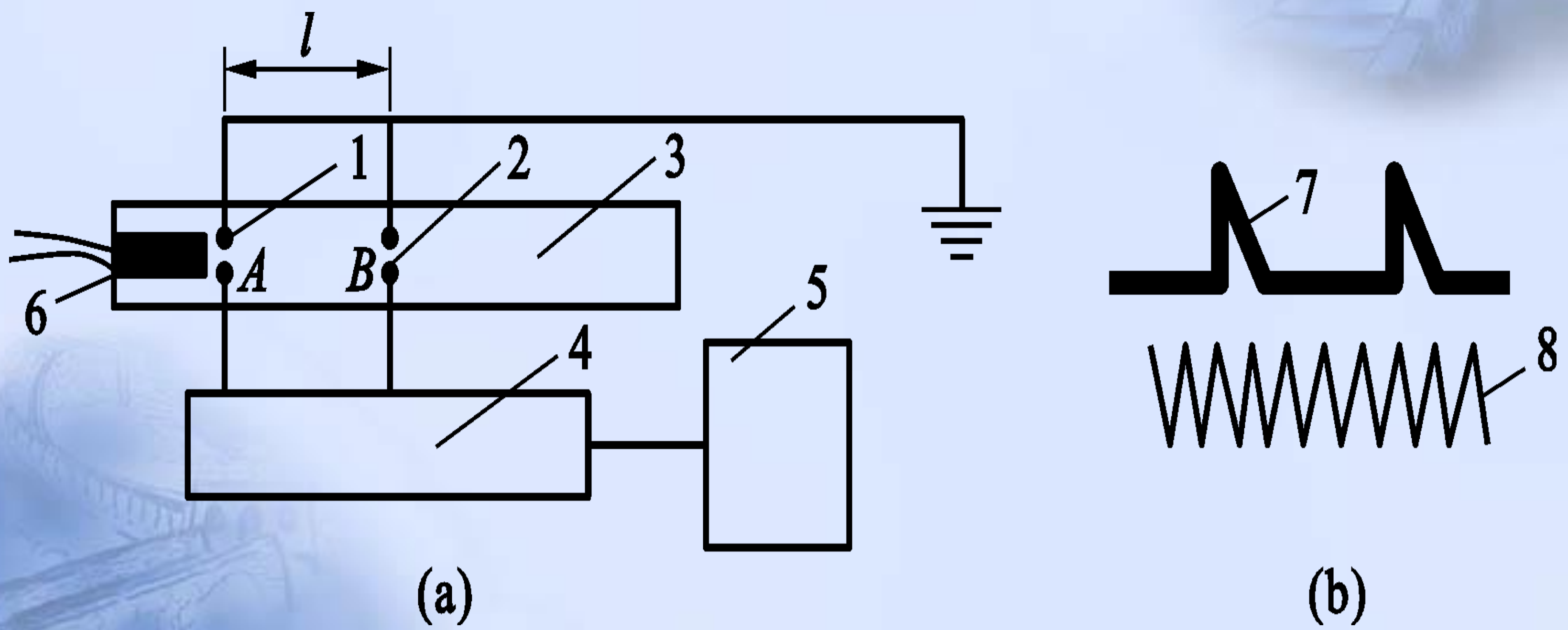
Detonation velocity measurement by fuse primer method



Detonation velocity measurement by fuse primer method

1—detonator；2—charge；3—fuse；4—lead plate

Detonation velocity measurement by OSC (oscilloscope)



Detonation velocity measurement by OSC

（a） measurement set-up； （b） wave pattern on screen

1，2—probe；3—charge；4—pulse signal generator；

5—OSC；6—detonator；7—pulse signal；8—time scale

Power of Explosive

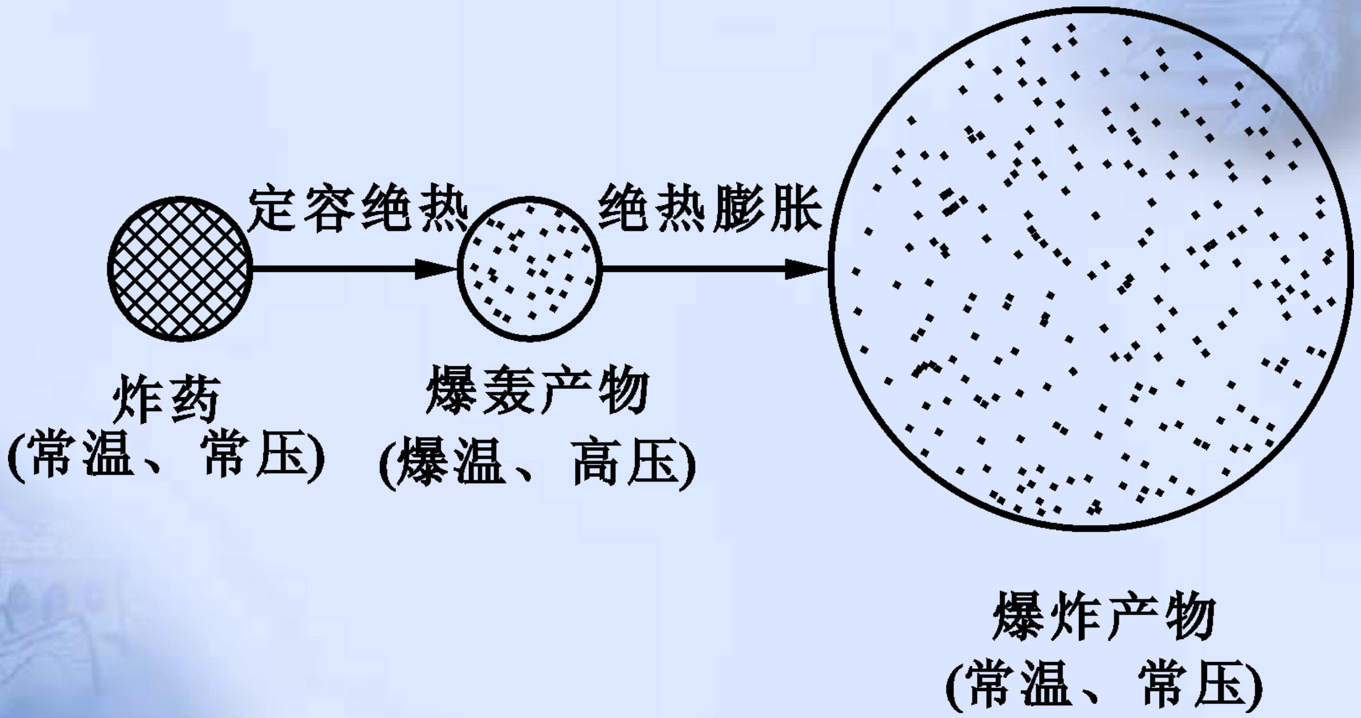


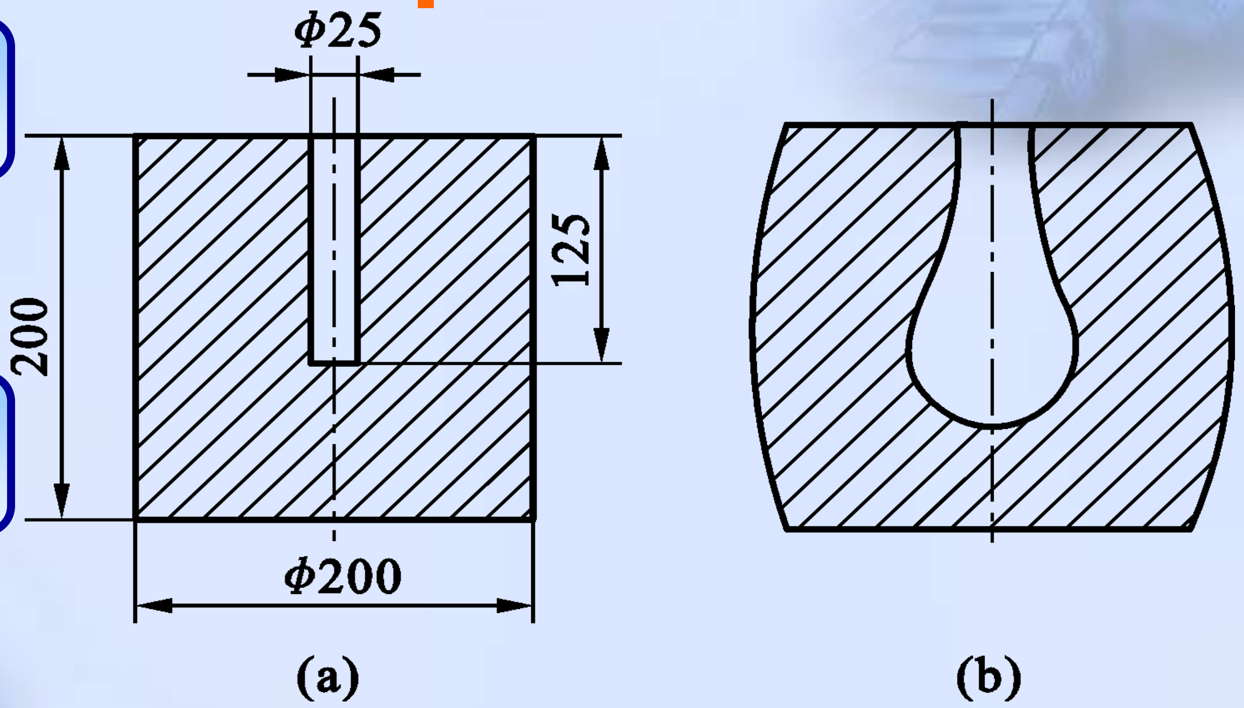
Diagram of explosion working

Measurement method of explosive power（1）

Lead block test

Ballistic pendulum test

Crater test



Lead block test

Measurement method of explosive power（2）

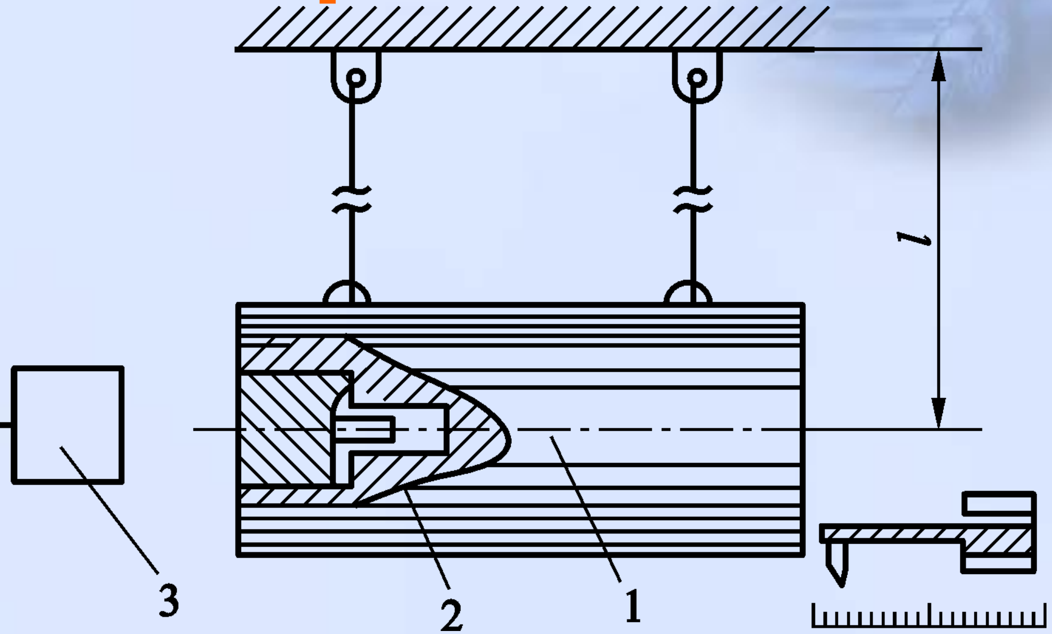
Lead block test

↓

Ballistic pendulum test

↓

Crater test



Ballistic pendulum test

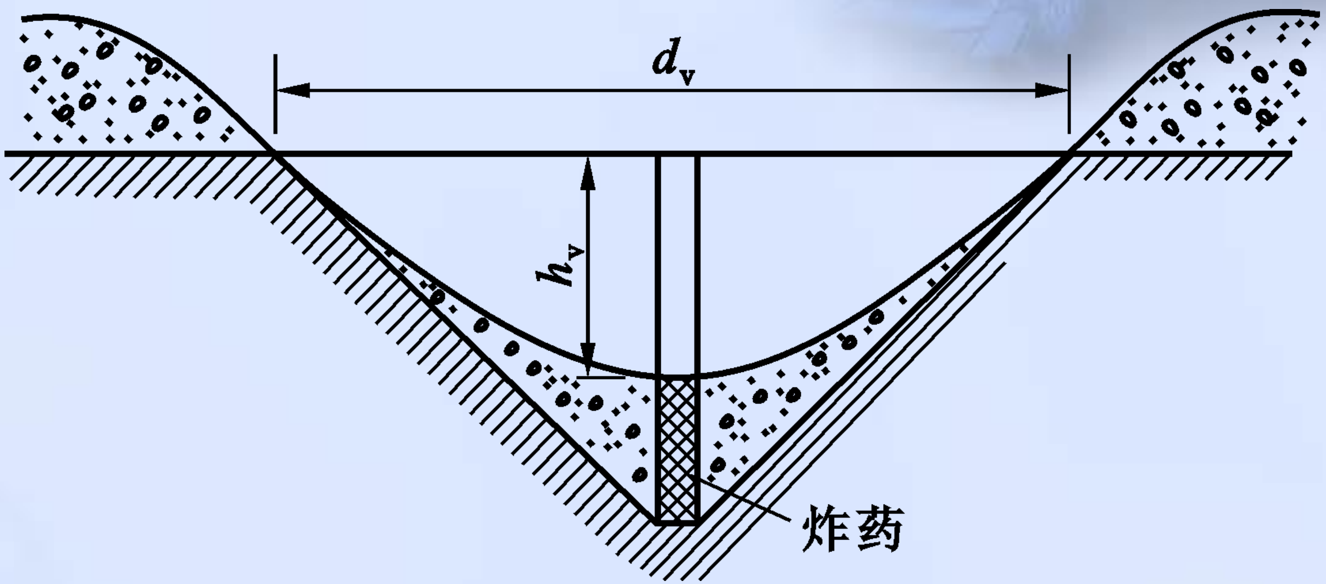
——pendulum 2——normal room 3——piston type projectile body

Measurement method of explosive power（3）

Lead block test

[Ballistic pendulum test]

Crater test



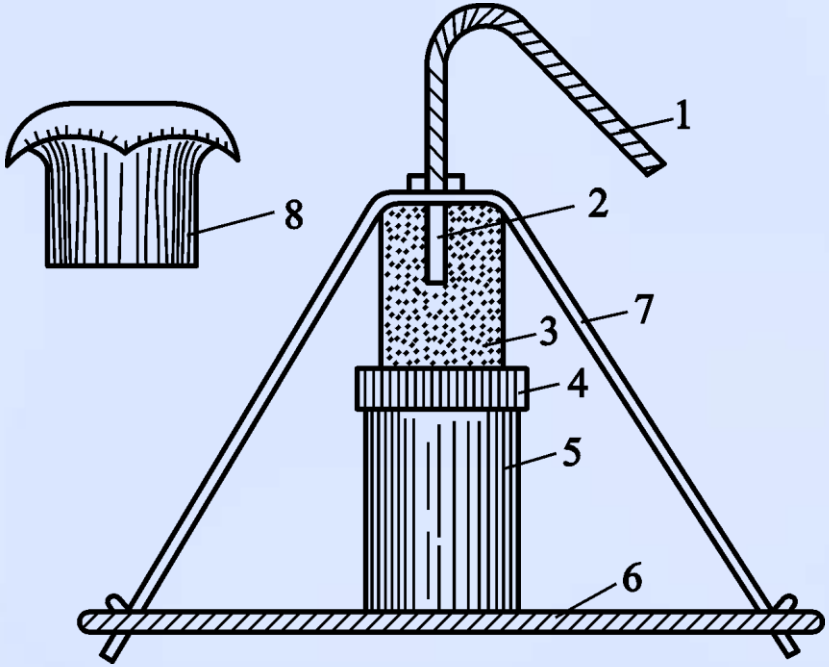
Crater test

Brisance of explosive and its measurement

explosive brisance

Explosive briancemeans the abilities of impact, breakthrough and breakup of detonation wave and products to the adjacent local solid medium at the instant time of explosion. It represents the dynamic effect of explosive.

Measurement of explosive brisance



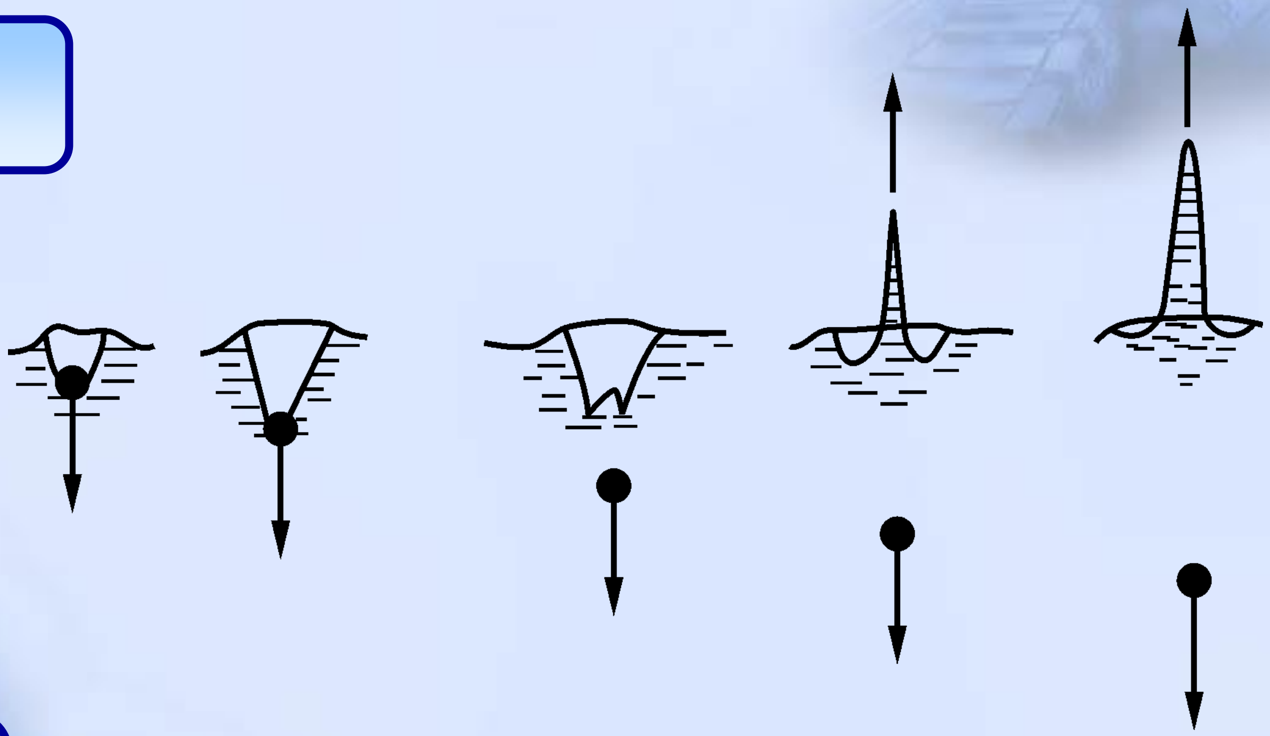
1——fuse； 2——detonator；
3——explosive； 4——steel sheet；
5——lead block； 6——steel plate；
7——thin string； 8——lead block after explosive

Cavity effect—phenomenon

Cavity phenomenon

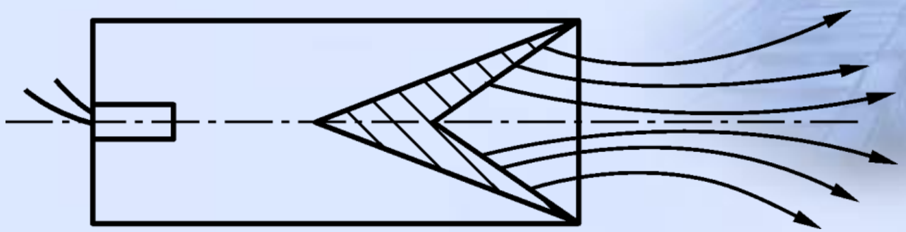
Cavity charge

Application of cavity effect

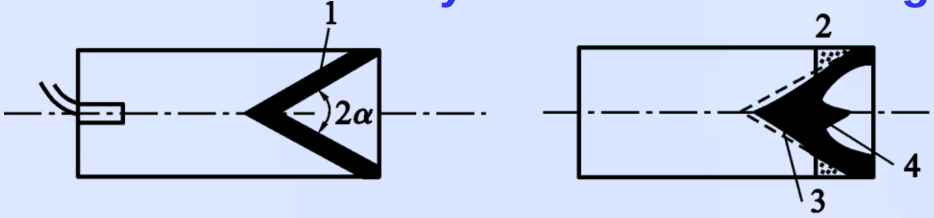


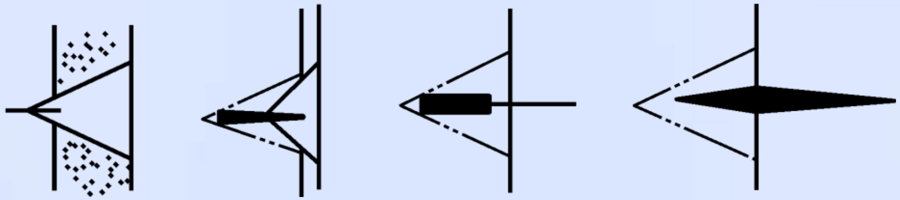
Formation of cumulative current on the water

Cavity—Charge



Formation of cumulative current when cavity locates in the charge front





Cavity charge with metal shaped charge liner and forms of metal jet flow

1—**shaped charge liner** (cavity liner) 2—detonation wave front 3—pestle 4—jet flow

Cavity Effect-Application

Cavity phenomenon

Cavity charge

Application of cavity effect

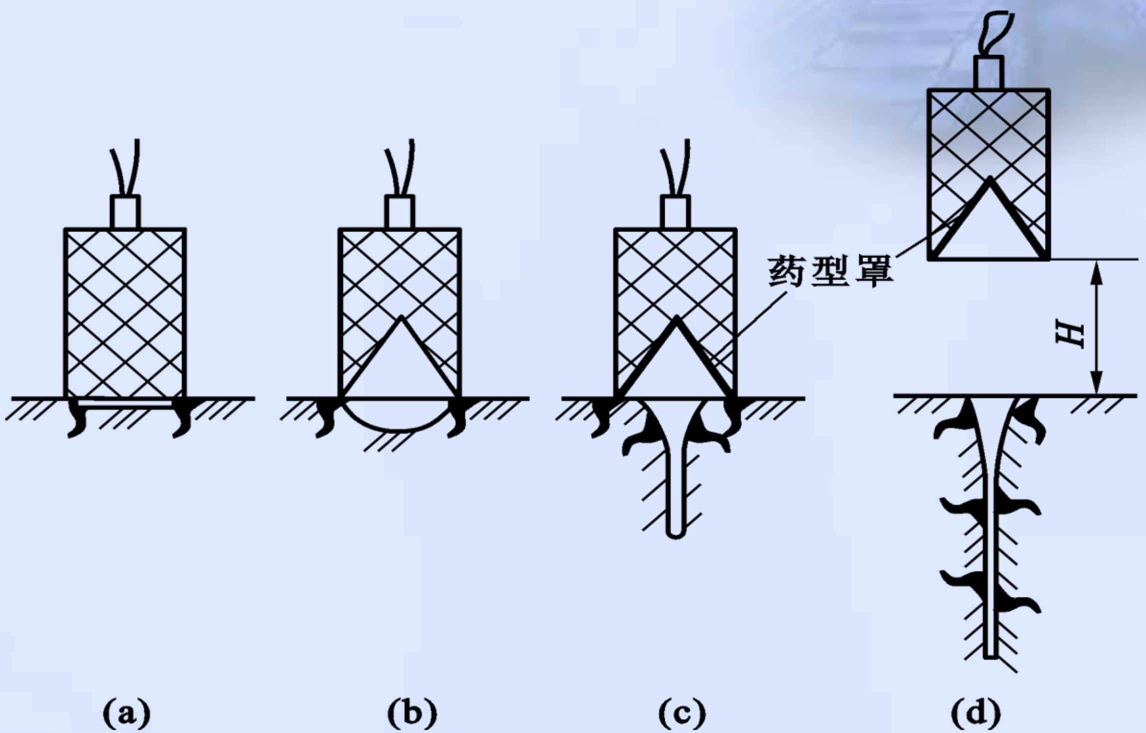


Plate perforation ability of different charge structure

（a） grain with flat bottom （b） grain with cavity

（c） cavity grain with shaped charge line

（d） cavity grain which have stand-off distance with steel pla

This chapter Questions

1. Interpretation of terms：

Slow decomposition, oxygen balance, detonation products, explosion products, detonation pressure, explosion pressure, explosive sensitivity, transmission distance , detonation velocity, detonation wave, explosive power, brisance ,cavity effect, pipe effect ,critical diameter, limit diameter, ideal detonation, steady detonation.

2. What are the three elements of a chemical explosion?

3. Discussing the conversion process from slow decomposition to detonation.

4. Discussing the classification and meaning of oxygen balance and its application in practical blasting works

5. Discussing the measurement methods, the factors and research significance of transmission distance.

6 Discussing the factors of explosives sensitivity briefly.

7. Discussing the hotspot formation mechanism with the mechanical effect.

8. Describing the detonation wave structure its propagation process.

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9. Describing the factors of the detonation velocity briefly.

Thank You !

Wuhan University of Technology