Answers

1. FOX-7: \[
\begin{align*}
H_2N & \quad C=\quad C=\quad NO_2 \\
H_2N & \quad C=\quad C=\quad NO_2
\end{align*}
\]

PETN: \[
\begin{align*}
O_2N & \quad O-H \quad C \quad CH_2 \quad O \quad NO_2 \\
O_2N & \quad O-H \quad C \quad CH_2 \quad O \quad NO_2
\end{align*}
\]

RDX: \[
\begin{align*}
O_2N & \quad N \quad C \quad N \quad NO_2 \\
H_2C & \quad N \quad C \quad N \quad NO_2
\end{align*}
\]

2. 4.3 m

3. single base gun propellant: NC (12.5 %)
   double base gun propellant: NC : NG (50 : 50)
   triple base gun propellant: NC : NG : NQ (25 : 25 : 50)

4. One fundamental problem for formulations containing red phosphorus and magnesium, in particular in formulations which contain a substoichiometric quantity of oxidizer is that a thermodynamically favourable side-reaction between the phosphorus and the magnesium can occur:
   \[
   2 \text{P} + 3 \text{Mg} \rightarrow \text{Mg}_3\text{P}_2
   \]

   The magnesiumphoshide that is subsequently formed can react with atmospheric moisture to form phosphine which is toxic:
   \[
   \text{Mg}_3\text{P}_2 + 6 \text{H}_2\text{O} \rightarrow 3 \text{Mg(OH)}_2 + 2 \text{PH}_3
   \]
This unwanted reaction can also occur very slowly if smoke munition is stored for several years, which can result in a considerable contamination of the munition depot (mainly bunkers or tunnel-shaped caves) with gaseous PH₃.

5. enthalpies of formation: Gaussian09
detonation parameters: EXPLO5
Cheetah 5.0

6. For a compound with the general formula CₐH₆N₆O₆d, the oxygen balance Ω (in %) is defined as follows:

\[
Ω_{CO₂} = \frac{[d - (2a) - (b / 2)] \times 1600}{M}
\]

\[
d = 6
\]
\[
a = 2
\]
\[
b = 4
\]
\[
M = 152
\]
\[
Ω = 0
\]

7. \( \sqrt{2E} = \frac{3\sqrt{3}}{16} D ≈ \frac{D}{3.08} \)

\( \sqrt{2E} = 2922 \text{ m s}^{-1} \)

8. DU

reason: Higher density of DU. The Bernoulli equation shows the relationship between the penetration depth (P) and the length of the penetrator (L) with the densities of the penetrator (\( \rho_p \)) and the target (\( \rho_T \)):

\[
P \sim L \sqrt{\frac{\rho_p}{\rho_T}}
\]

9. The N₂/CO ratio should be high.

\( T_c \) should be low.

10. The impact energy is: \( E = \text{energy} = \text{work} \times \text{distance} = \text{mass} \times \text{acceleration} \times \text{distance} \), therefore: \( E = 5 \text{ kg} \times 9.81 \text{ m s}^{-2} \times 0.5 \text{ m} = 24.5 \text{ kg m}^2 \text{ s}^{-2} = 24.5 \text{ Nm} = 24.5 \text{ J} \)

11. – mixed acid
– nitric acid, HNO₃ (65–100%)
– dinitrogen pentoxide, N₂O₅
– NO₂⁻BF₄⁻, nitronium tetrafluoroborate
– NO₂⁻OSO₂CF₃, nitronium triflate
also: Ag salts, AgNO₃, AgNO₂ or KNO₂ / oleum (H₂SO₄/SO₃)
12. – for bipropellants in rocket propulsion, especially but not exclusively for pulsed mode operation
– for incendiary devices

13. DNAN = dinitroanisole
   or
   IMX-101: DNAN = dinitroanisole (binder) + NTO (filler)

14. IMX-104: DNAN (binder) + NTO and RDX (filler)

15. \( I_{sp} \approx \sqrt{\frac{T_C}{M}} \)

16. \( \mathcal{F} = I_{sp} \frac{\Delta m}{\Delta t} \)

Where \( I_{sp} \) is the specific impulse in \( \text{m s}^{-1} \), \( \Delta m \) is the mass of used propellant (in kg) and \( \Delta t \) is the duration of burning of the engine (in s).

17. double-base: NC/NG formulation (homogeneous)
   composite: AP, Al, HTPB binder (heterogeneous)

18. 20 s

19. This is the NIR range. Suitable metals are Cs (caesium) and K (potassium)

20. Kamlet-Jacobe equation: \( p_{C-J} \ [\text{kbar}] = K \rho_0\Phi \rho_{C-J} \propto \rho_0 \)

21. Both values can be estimated using the Trouton’s rule, whereby \( T_m \) is the melting point of the solid and \( T_b \) is the boiling point of the liquid:
   \[ \Delta H_{\text{sub}}\ [\text{J mol}^{-1}] = 188 \ T_m\ [\text{K}] \]
   \[ \Delta H_{\text{vap}}\ [\text{J mol}^{-1}] = 90 \ T_b\ [\text{K}] \]

22. The Bernoulli equation shows the relationship between the penetration depth (P) and the length of the penetrator (L) with the densities of the penetrator (\( \rho_P \)) and the target (\( \rho_T \)):
   \[ P \sim L \sqrt[3]{\frac{\rho_P}{\rho_T}} \]

Therefore the penetration depth depends on the density of the penetrator.
23. The Gurney velocity \( \sqrt{2E} \) and the detonation velocity \( (D = V_d) \) of an explosive can be described approximately using the following simple relationship:

\[
\sqrt{2E} = \frac{3\sqrt{3}}{16} D = \frac{D}{3.08}
\]

24. Technical \( N_2O_5 \) was previously mainly obtained by the dehydration of nitric acid at \(-10^\circ C\), as \( N_2O_3 \) is the anhydride of nitric acid. It is an easily sublimed solid (subl. \( 32^\circ C \), 1 bar).

\[
4 \text{HNO}_3 + \text{P}_4\text{O}_{10} \rightarrow 2 \text{N}_2\text{O}_4 + 4 \text{H}_3\text{PO}_4
\]

Since 1983, the technical synthesis usually used follows that developed by Lawrence Livermore National Laboratory, in which the electrolysis of nitric acid in the presence of \( N_2O_4 \) results in the formation of a ca. 15–20% solution of \( N_2O_5 \) in anhydrous nitric acid.

\[
2 \text{HNO}_3 + \text{N}_2\text{O}_4 \rightarrow 2 \text{N}_2\text{O}_5 + \text{H}_2\text{O}
\]

Pure and almost acid-free \( N_2O_5 \) can be obtained from the gas-phase ozonation of \( N_2O_4 \) using an ozone-oxygen mixture with a ca. 5–10% ozone content.

\[
\text{N}_2\text{O}_4 + \text{O}_3 \rightarrow \text{N}_2\text{O}_5 + \text{O}_2
\]

25. ADN is synthesized by the nitration of ammonia using \( N_2O_5 \) (prepared by the ozonation of \( NO_2 \)) in a chlorinated solvent:

**Synthesis of \( N_2O_5 \):**

\[
2 \text{NO}_2 + \text{O}_3 \rightarrow \text{N}_2\text{O}_5 + \text{O}_2
\]

**Synthesis of ADN:**

\[
\begin{align*}
\text{NH}_3 + N_2O_5 & \rightarrow (O_2N)NH_2 + HNO_3 \\
(O_2N)NH_2 + N_2O_5 & \rightarrow (O_2N)_2NH + HNO_3 \\
(O_2N)_2NH + NH_3 & \rightarrow [NH_4][N(NO_2)_2]^- \\
2 HNO_3 + 2 NH_3 & \rightarrow 2 [NH_3][NO_3]^-
\end{align*}
\]

\[
4 \text{NH}_3 + 2 N_2O_5 \rightarrow [NH_3][N(NO_2)_2]^- + 2 [NH_3][NO_3]^-
\]

26. The biocidal activity of HF exceeds both \( Cl_2 \) and \( HCl \). 200 ppm HF destroy most bacteria, including Anthrax spores.

27. \( \text{M}_2\text{O}_3 + \text{Al} \rightarrow \text{M} + \text{Al}_2\text{O}_3 \)

28. Lead-free tetrazolate based primary explosive are:

- \( \text{Cu(I)} \) nitrotetrazolate, DBX-1
- \( \text{Cu(II)} \) 1-methyl-5-nitriminotetrazolate
- \( [\text{Na}]_2[(\text{H}_2\text{O})_2\text{Cu(nitrotetrazolate)}_4] \)
29. Bis(trinitroethyl)-1,2,4,5-tetrazine-3,6-diamine (BTAT)

\[
\begin{align*}
\text{O}_3\text{N} & \quad \text{O}_3\text{N} \\
\text{N} & \quad \text{N} \\
\text{N} & \quad \text{N} \\
\text{H} & \quad \text{N} \\
\text{N} & \quad \text{H} \\
\text{N} & \quad \text{O}_2\text{N} \\
\text{N} & \quad \text{O}_2\text{N} \\
\text{N} & \quad \text{O}_2\text{N} \\
\text{N} & \quad \text{N} \\
\text{N} & \quad \text{H} \\
\text{N} & \quad \text{O}_2\text{N} \\
\end{align*}
\]

30. Decrease of thyroxin synthesis due to inhibition of iodine storage.

31. Underwater operations, torpedo propulsion.

32. Solid rocket motor: 3000–4000 bar
   Large calibre gun: 40–70 bar

33. a) 
   – heat of explosion \(Q\) (in \(\text{kJ kg}^{-1}\)),
   – detonation velocity \(D\) (in \(\text{m s}^{-1}\)),
   – detonation pressure \(P\) (in kbar),
   and less importantly,
   – explosion temperature \(T\) (K) and
   – volume of gas released \(V\) per kg explosive (in \(\text{L kg}^{-1}\)).

   b) 
   – the specific energy \(f_E\) or force or impetus \((f_E = nRT)\),
   – the combustion temperature \(T_c\) (K),
   – the co-volume \(b_E\) (in \(\text{cm}^3 \text{ g}^{-1}\))
   – the pressure \(p\) (bar; 3000–4000 bar).

   c) 
   The most important performance parameter is the specific impulse \(I_{sp}\), or \(I_{sp}^*\) with:
   \[
   I_{sp}^* = \frac{I_{sp}}{g}
   \]
   The average thrust of a rocket \(F\) can in accordance with the equation above be given simply as:
   \[
   F = I_{sp} \frac{\Delta m}{\Delta t}
   \]

34. – The combustion temperature \(T_c\), which should be low.
   – The \(\text{N}_2/\text{CO}\) ratio of the combustion gases, which should be high.
35. Target penetration of an EFP is much less than that of a jet (SC), but the hole diameter is larger with more armour backspall.

36. The gap test.

37. The fast cook-off test.

38. | advantage                       | disadvantage                                      |
    | RDX            | Higher performance                                | Lower thermal stability than HNS, Higher sensitivity than HNS |
    | HNS            | Higher thermal stability, Lower sensitivity       | Lower performance                                      |

39. – very high sensitivity
    – high vapour pressure (volatile)

40. a) isochoric
    b) isobaric
    c) isochoric

41. a) SrCl
    SrOH
    b) BaCl
    BaOH
    Ba

42. In accordance with the rule of Wien, the maximum wavelength of the blackbody radiation \( \lambda_{\text{max}} \) (\( \mu \text{m} \)) shifts towards shorter wavelengths (higher energy) with increasing temperature:

\[
\lambda_{\text{max}} = 2897.756 \, \mu\text{m} \cdot K \cdot T^{-1}
\]

43. The burn rate increases with increasing pressure:

\[
r = \beta p^a
\]

In this context, \( \beta \) is a coefficient (\( \beta = f(T) \)) and \( a \) is the index of the burn rate which describes the pressure dependency. The index \( a \) is < 1 for energetic materials which deflagrate and > 1 for detonating explosives.

44. Usually (at least in the \( \mu \text{m} \) region) smaller particles show a much higher sensitivity towards electrostatic discharge.
45. The main advantage of the EFP over a conventional shaped charge is its effectiveness at very large standoff distances, equal to hundreds of times the charge’s diameter (perhaps a hundred meters for a practical device):

46. At high temperatures CO is thermodynamically favored over CO₂ according to the Boudouard equilibrium:

\[ \text{CO}_2(g) + \text{C}(s) \rightleftharpoons 2 \text{CO}(g) \quad \Delta H^\circ = +173 \text{ kJ mol}^{-1} \]

47. - oxidation of the carbon back-bone, e.g. TNT
- introduction of ring or cage strain, e.g. CL-20
- highly endothermic, nitrogen-rich compounds, e.g. TAGzT

48. nitro: TNT, HNS
nitrate (nitrate ester): NG
nitramino: RDX, HMX
nitrirmino: TAG 1-MNT
azide: Pb(N₃)₂
peroxo: TATP
49. – in pure (liquid) form too sensitive,
  – crystallizes at about 13 °C,
  – In save to handle formulations (e.g. dynamite) too low performance.

50. Kamlet and Jacobs suggested an empirical relationship between the detonation velocity and the **detonation pressure**. In this, the detonation velocity $D$ is linear and the detonation pressure $p_{\text{C-J}}$ to the power of two dependent on the loading density $\rho_0$ (in g cm$^{-3}$):

$$
\begin{align*}
 p_{\text{C-J}} \ [\text{kbar}] &= K \rho_0^2 \Phi \\
 D \ [\text{mm \ \mu s}^{-1}] &= A \Phi^{0.5} (1 + B \rho_0)
\end{align*}
$$

The constants $K$, $A$ and $B$ are defined as follows: $K = 15.88$

- $A = 1.01$
- $B = 1.30$

The value $\Phi$ is therefore

$$
\Phi = N (M)^{0.5} (Q)^{0.5}
$$

where
- $N$ is the moles of gas released per gram of explosive,
- $M$ is the mass of gas in gram per mole of gas and
- $Q$ is the heat of explosion in cal per gram.