23.1 LATTICE ENERGIES AND BORN-HABER CYCLES

1. Write an equation for the process corresponding to the **second** ionisation energy of calcium.
   Include state symbols.

   ..... [1]

Lattice energy

2. Define lattice energy, ΔH_{latt}.

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   ..... [2]

Electron Affinity (EA)

3. Define the first electron affinity.

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   ..... [2]

   Define the term *electron affinity*.

4. Write an equation for the process corresponding to the second electron affinity of sulfur.
   Include state symbols.

   ..... [1]

5. Suggest why the first electron affinity of oxygen is negative.

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   ..... [1]

6. Suggest why the second electron affinity of oxygen is positive.

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   ..... [1]

7. The first electron affinity of an atom is usually an exothermic process, whereas the second electron affinity is an endothermic process.
   Suggest why.

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   ..... [1]

8. Describe the general trend in first electron affinities for C*l*, Br, and I. Explain your answer.

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   ..... [2]

9. Table 1.3 shows some data relevant to the silver(I) halides, AgCl to AgI.

silver(I) halide	Electron affinity of halogen/ kJ mol^{-1}	lattice energy/ kJ mol^{-1}
AgCl	–349	–905
AgBr	–325	–890
AgI	–295	–876

Explain the trend in the first electron affinities of the halogens, Cl to I. [2]

10. Describe the trend in the first electron affinity of the Group 16 elements S to Te.
Explain your answer.

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…… [2]

11. The electron affinity of C(g), is –120 kJ mol^{-1}.
The electron affinity of F(g) is –348 kJ mol^{-1}
Suggest an explanation for the difference between the electron affinity of fluorine and the electron affinity of carbon.

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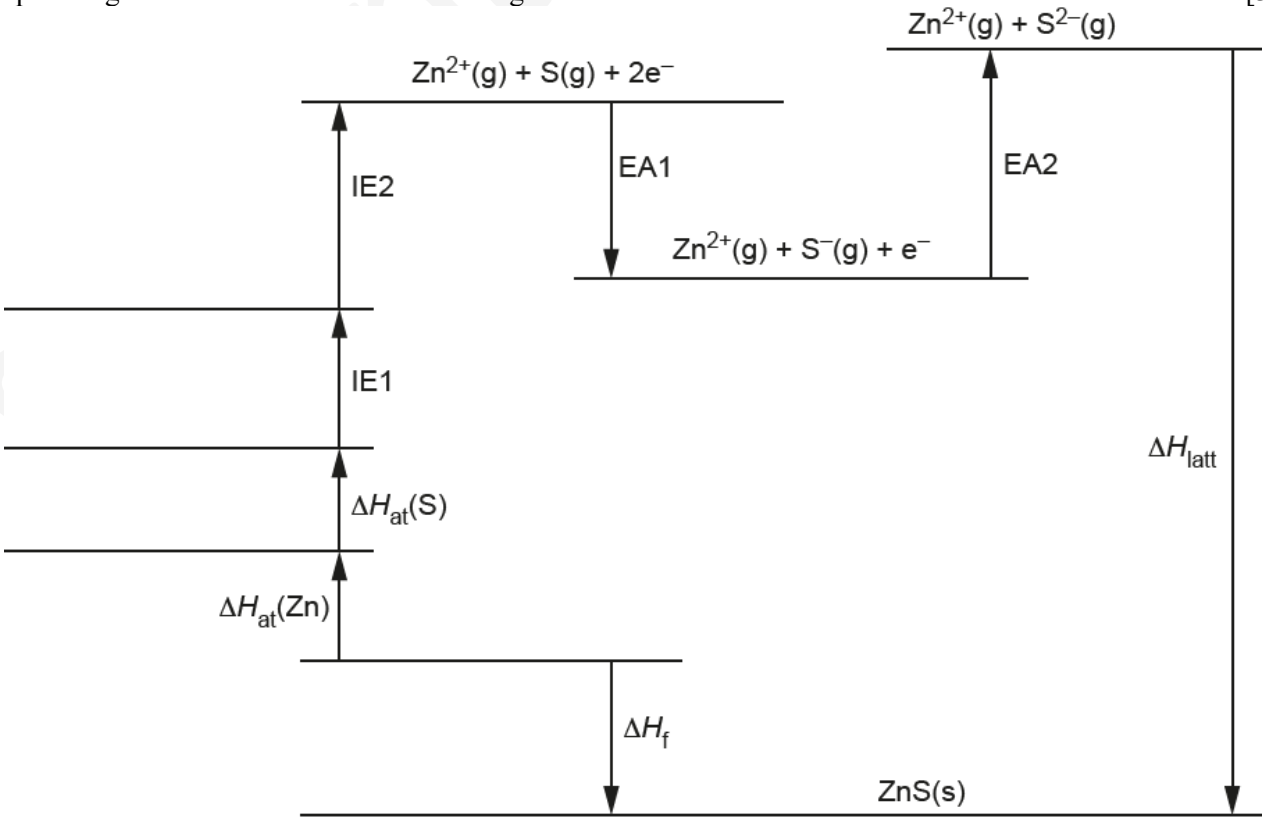
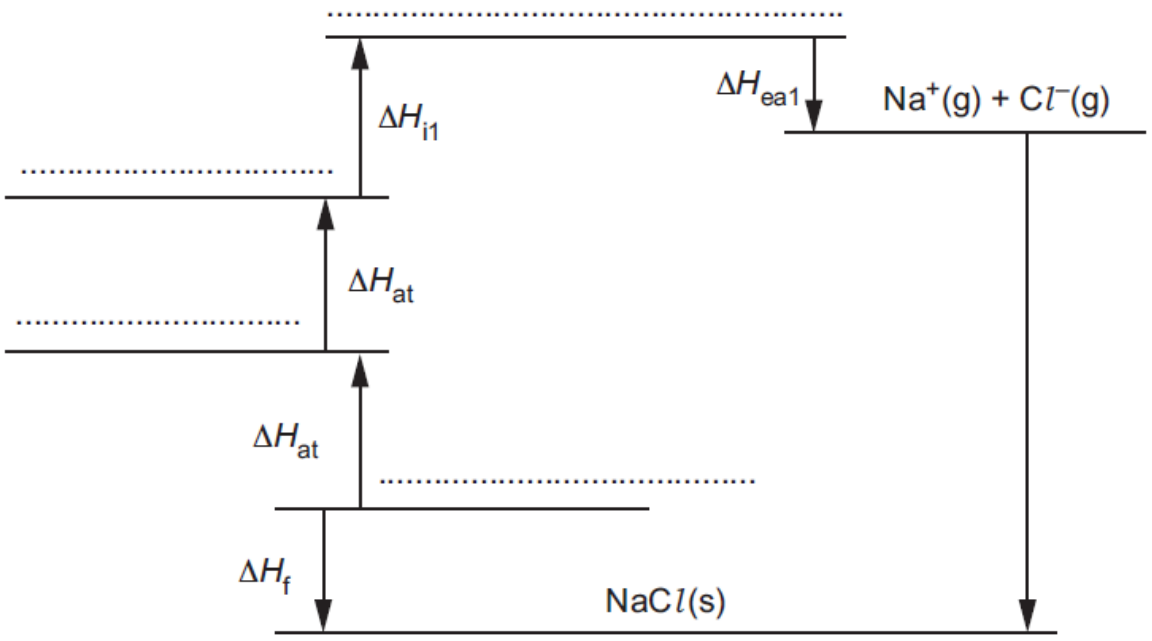
…… [1]

Born-Haber cycles

12. Complete Fig. 1.2 to show the Born–Haber diagram for the ionic solid ZnS. [3]



13. Complete the Born–Haber cycle in Fig. 8.1 for the ionic solid NaCl.
Include state symbols of relevant species. [3]



Key

ΔH_{i1} first ionisation energy

ΔH_{ea1} first electron affinity

Fig. 8.1

14. Table 1.1 shows some energy changes.

Table 1.1

energy change	value / kJ mol^{-1}
standard enthalpy change of atomisation of potassium	+89
first ionisation energy of potassium	+419
second ionisation energy of potassium	+3070
standard enthalpy change of atomisation of sulfur	+279
S–S bond energy	+265
first ionisation energy of sulfur	+1000
second ionisation energy of sulfur	+2260
first electron affinity of sulfur	–200
second electron affinity of sulfur	+640
standard enthalpy change of formation of potassium sulfide, $K_2S(s)$	–381

i) Born–Haber cycles can be used to determine the lattice energies of ionic compounds. Complete the Born–Haber cycle in Fig. 1.1 for potassium sulfide, $K_2S(s)$. Include state symbols for all of the species.

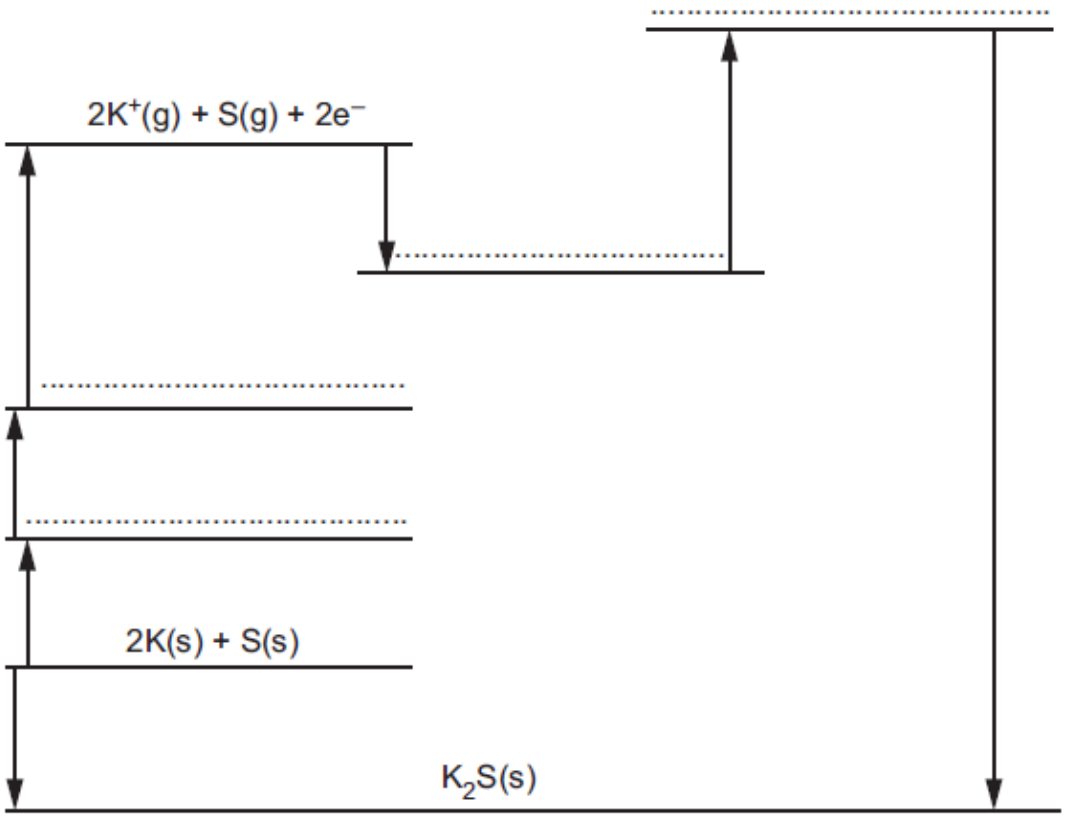


Fig. 1.1

[3]

ii) Calculate the lattice energy, ΔH°_{latt}, of $K_2S(s)$ using relevant data from Table 1.1. Show your working.

ΔH_{latt} of $K_2S(s)$ = ...(ans = –2116)..... kJ mol^{-1} [2]

15. The following table gives data relevant to the Born–Haber cycle for silver(I) fluoride, AgF.

standard energy change	value / kJ mol^{-1}
first ionisation energy of silver	+732
enthalpy change of atomisation of silver	+289
enthalpy change of atomisation of fluorine	+79
enthalpy change of formation of silver(I) fluoride	–203
lattice energy of silver(I) fluoride	–955

Calculate the first electron affinity, EA_1, of fluorine, using data from the above table.
It may be helpful to draw a labelled energy cycle as part of your working for your answer.

EA_1 = ...(ans = -348)..... kJ mol^{-1} [2]

16. Table 3.1 shows energy changes to be used in this question.

energy change	value/ kJ mol^{-1}
standard enthalpy change of atomisation of zinc	+131
first ionisation energy of zinc	+906
second ionisation energy of zinc	+1733
standard enthalpy change of formation of $ZnI_2(s)$	–208
lattice energy, , of zinc iodide, $ZnI_2(s)$	–2605
first ionisation energy of iodine	+1008
second ionisation energy of iodine	+1846
I–I bond energy	+151
enthalpy change of sublimation of iodine, $I_2(s) \rightarrow I_2(g)$	+62

Calculate the first electron affinity for iodine. Use relevant data from Table 3.1 in your working.
It may be helpful to draw a labelled energy cycle.
Show all working.

first electron affinity for iodine = ... (ans= -293) ..... kJ mol^{-1} [3]

17. Table 3.2 shows some energy changes.

energy change	value / kJ mol^{-1}
standard enthalpy change of atomisation of silver	+285
first ionisation energy of silver	+731
second ionisation energy of silver	+2074
bond energy of O=O	+496
bond energy of O–O	+150
first electron affinity of oxygen	–141
second electron affinity of oxygen	+798
first ionisation energy of oxygen	+1314
standard enthalpy change of formation of silver oxide, $Ag_2O(s)$	–31

Calculate the lattice energy, $\Delta H^{\ominus}_{latt}$, of $Ag_2O(s)$ using relevant data from Table 3.2.
It may be helpful to draw a labelled energy cycle.
Show your working.

$\Delta H^{\ominus}_{latt}$ of $Ag_2O(s)$ = ...(ans= -2968)..... kJ mol^{-1} [3]

18. Calcium chloride, $CaCl_2$, is an ionic solid.
The values of some energy changes are shown in Table 1.1.

energy change	value / kJ mol^{-1}
lattice energy, $\Delta H^{\ominus}_{latt}$, $CaCl_2(s)$	–2237
standard enthalpy change of atomisation of calcium	+193
first ionisation energy of calcium	+590
second ionisation energy of calcium	+1150
standard enthalpy change of atomisation of chlorine	+121
first electron affinity of chlorine	–364

(i) Use the data in Table 1.1 to calculate the standard enthalpy change of formation, $\Delta H^{\ominus}_{f}$, of calcium chloride. It may be helpful to draw an energy cycle. Show all your working.

$\Delta H_f^{\ominus}$ ($CaCl_2(s)$) = ...(ans= -790)..... kJ mol^{-1} [2]

(ii) Three possible values for the first electron affinity of bromine are shown in Table 1.2. One of them is correct. Place a tick by the correct value. Explain your choice.

possible values	Place one tick (✓) in this column
–342 kJ mol^{-1}	
–364 kJ mol^{-1}	
–386 kJ mol^{-1}	

explanation .....

……..... [1]

19. Radium is a Group 2 element.
Some data relating to radium and sulfur are listed. Select relevant data from this list for use in your answer.

process	value / kJ mol^{-1}
enthalpy change for $Ra(s) \rightarrow Ra^{2+}(g) + 2e^-$	+1619
first ionisation energy of sulfur	+1000
second ionisation energy of sulfur	+2260
first electron affinity of sulfur	–200
second electron affinity of sulfur	+532
enthalpy change for $\frac{1}{8}S_8(s) + 2e^- \rightarrow S^{2-}(g)$	+555
lattice energy of RaS(s)	–2612

(i) Calculate the standard enthalpy change of formation, $\Delta H_f^{\ominus}$, of radium sulfide.

standard enthalpy change, $\Delta H_f^{\ominus}$ = ...(ans= -438)..... kJ mol^{-1} [2]

(ii) Sulfur exists as S_8 molecules in the solid state.
Use the data in this question to calculate the enthalpy change for the reaction $S_8(s) \rightarrow 8S(g)$.

enthalpy change = ...(and = +1784)..... kJ mol^{-1} [3]

20. The equation for the formation of a gaseous sulfate ion is shown.

$S(s) + 2O_2(g) + 2e^- \rightarrow SO_4^{2-}(g)$ $\Delta H = {}^{\Delta}H_f^{\ominus}$ of $SO_4^{2-}(g)$

Calculate the standard enthalpy change of formation, ${}^{\Delta}H_f^{\ominus}$, of $SO_4^{2-}(g)$. It may be helpful to draw a labelled energy cycle. Use relevant data from Table 1.1 in your calculations.

energy change	value / kJ mol^{-1}
lattice energy of barium sulfate, $BaSO_4(s)$	–2469
standard enthalpy change of formation of barium sulfate	–1473
standard enthalpy change of atomisation of barium	+180
first ionisation energy of barium	+503
second ionisation energy of barium	+965
standard enthalpy change of atomisation of sulfur	+279
standard enthalpy change for $S(g) \rightarrow S^{2-}(g)$	+440
standard enthalpy change for $O(g) \rightarrow O^{2-}(g)$	+657
O=O bond energy	+496

${}^{\Delta}H_f^{\ominus}$ of $SO_4^{2-}(g)$ = ... (ans = -652) ..... kJ mol^{-1} [3]

21. Some data relating to calcium and oxygen are listed. Select relevant data from this list for your answers to parts (c), (d) and (e).

process	value / kJ mol–1
first ionisation energy of oxygen	+1310
second ionisation energy of oxygen	+3390
first electron affinity of oxygen	–142
second electron affinity of oxygen	+844
enthalpy change for $\frac{1}{2} O_2(g) + 2e^- \rightarrow O^{2-}(g)$	+951
enthalpy change for $Ca(s) \rightarrow Ca^{2+}(g) + 2e–$	+1933
lattice energy of CaO(s)	–3517

(a) Oxygen exists as O_2 molecules.

Use the data in this question to calculate a value for the bond energy of the O=O bond.

Show all your working.

bond energy = ...(ans = 498)..... kJ mol^{-1} [3]

(b) Calculate the enthalpy of formation of calcium oxide, CaO(s).

enthalpy of formation = ... (ans = - 633) ..... kJ mol^{-1} [2]

Factors Affecting Lattice Energy

22. State and explain the main factors that affect the magnitude of lattice energies.

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..... [2]

23. Explain the reasons why the lattice energy of $MgCl_2$ is more exothermic than the lattice energy of KC*l*.

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..... [2]

24. Explain why the lattice energy, ΔH_{latt}, of ZnO is more exothermic than that of ZnS.

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…… [2]

25. Identify the factor that causes the lattice energy of calcium oxide to be more exothermic than that of lithium fluoride. Explain why this factor causes the difference in lattice energies.

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…… [2]

26. (i) State the two major factors that affect the numerical magnitude of a lattice energy. [2]

(ii) For each factor you have identified in (i), state whether it tends to make the lattice energy of radium sulfide more or less exothermic than that of sodium chloride.
Explain your answer.

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…… [2]

(iii) The lattice energies of sodium chloride, NaCl, and radium sulfide, RaS, are –771 kJ $mol^{-1}$and –2612 kJ mol^{-1}, respectively.
Identify the dominant factor in determining the relative numerical magnitudes of the lattice energies of radium sulfide and sodium chloride.
Explain your answer.

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…… [1]

27. Predict how of $\Delta H^{\ominus}_{latt}CdI_2(s)$ differs from $\Delta H^{\ominus}_{latt}$of $ZnI_2(s)$.
Place a tick (✓) in the appropriate box in Table 3.2.
Table 3.2

$\Delta H^{\ominus}_{latt}$ of $CdI_2(s)$ is less negative than $\Delta H^{\ominus}_{latt}$ of $ZnI_2(s)$	$\Delta H^{\ominus}_{latt}$ of $CdI_2(s)$ is the same as $\Delta H^{\ominus}_{latt}$of $ZnI_2(s)$	$\Delta H^{\ominus}_{latt}$ of $CdI_2(s)$ is more negative than $\Delta H^{\ominus}_{latt}$ of $ZnI_2(s)$

Explain your answer.

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..... [1]

28. State and explain how the lattice energy of FeO(s) compares to the lattice energy of CaO(s).

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…… [2]

Explain why the lattice energy of CaO is more exothermic than the lattice energy of LiF. [1]

29. The lattice energies of three ionic compounds are given.

compound	lattice energy / kJ mol^{-1}
LiF(s)	–1022
CaO(s)	–3513
SrO(s)	–3310

Use the data in the table to estimate approximate values for the lattice energies of magnesium oxide and barium oxide.

ΔH_{latt} MgO(s) = ... kJ mol^{-1}

ΔH_{latt} BaO(s) = ... kJ mol^{-1} [1]

State whether the lattice energy of $CaCl_2$(s) is more or less exothermic than the lattice energy of MgF_2(s).
Explain your answer. [1]

30. Suggest how the lattice energy of $BaSO_4$(s) differs from the lattice energy of Cs_2SO_4(s).
Explain your answer.

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…… [2]

Explain the trend in the lattice energies of the silver(I) halides, AgCl to AgI. [1]

31. Suggest the trend in the magnitude of the lattice energies of the Group 1 iodides, LiI, NaI, and KI.
Explain your answer.

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…… [2]

32. The ionic radius of Pb^{2+} is 0.120 nm compared to 0.133 nm for K^+.
Suggest how the $\Delta H_{latt}^{\ominus}$, of PbI_2(s) differs from $\Delta H_{latt}^{\ominus}$ of KI(s).
Explain your answer.

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…… [2]

33. Suggest the trend in the magnitude of the lattice energies of the silver compounds Ag_2S, Ag_2O, and Ag_2Se.
Explain your answer.

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least exothermic most exothermic

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.....[2]

34. Suggest the trend in the magnitude of the lattice energies of the metal nitrates, $NaNO_3(s)$, $Mg(NO_3)_2(s)$, and $RbNO_3(s)$.
Explain your answer.

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most exothermic least exothermic

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..... [3]

35. The lattice energies of $ZnBr_2$, $ZnCl_2$ and ZnO are shown.

Compound	lattice energy / kJ mol^{-1}
$ZnBr_2$	–2678
$ZnCl_2$	–2734
ZnO	–3971

(i) Explain why there is a difference between the lattice energies of $ZnBr_2$ and $ZnCl_2$. [1]

(ii) Explain why there is a difference between the lattice energies of $ZnCl_2$ and ZnO.

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..... [1]

36. The ionic radius of Pb^{2+} is 0.120 nm compared to 0.133 nm for K^+.
Suggest how the $\Delta H^{\ominus}_{latt}$ of $PbI_2(s)$ differs from $\Delta H^{\ominus}_{latt}$ of KI(s).
Explain your answer.

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..... [2]

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