UNIVERSITY OF TORONTO

FACULTY OF APPLIED SCIENCE AND ENGINEERING

April 29, 2023 — **Duration: 150 minutes**

First Year, MSE160 MOLECULES AND MATERIALS

Exam Type: B - Closed Book, aid sheets provided. Calculator from Faculty approved list permitted.

Examiners: J Nogami, SD Ramsay

First name (please write as legibly as possible within the boxes)

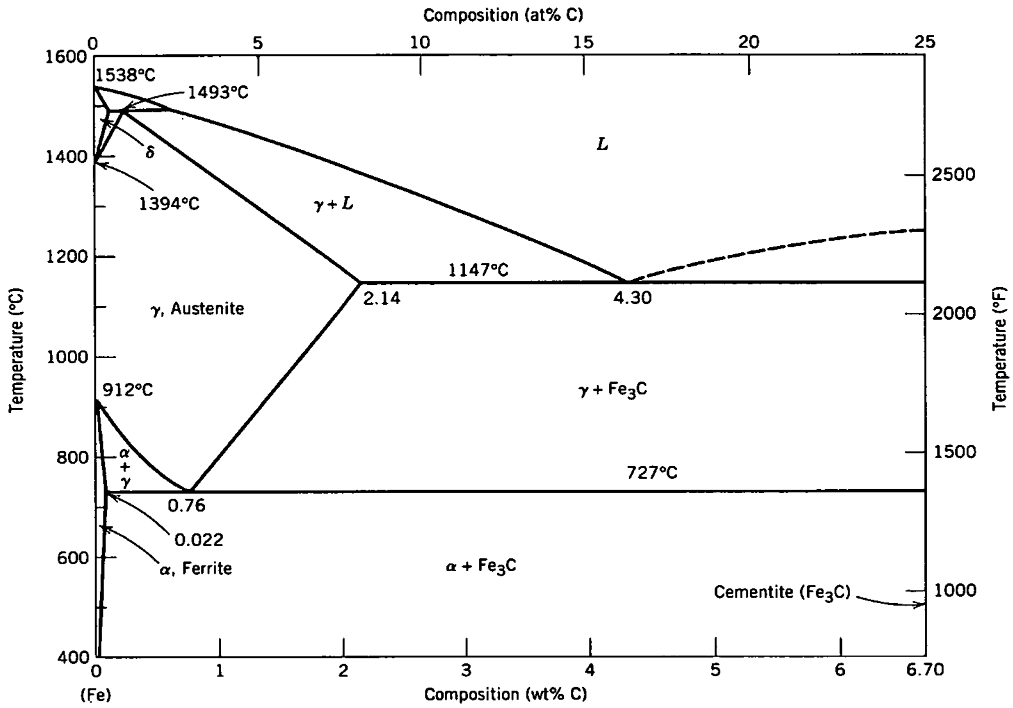
Last name

Student Number

IMPORTANT:

- On this page, write your name and student number clearly.
- On the computer answer form, complete all sections fully.
- Do not open this test booklet until instructed to do so.
- Numerical responses must be expressed in most appropriate units, including appropriate prefixes (ex. GPa rather than 10^9 Pa), and be written with appropriate significant figures.

1. These questions pertain to the $Fe - Fe_3C$ phase diagram below.



(a) (2 points) For an 1 kg sample of a 1.3 wt%C steel at 728 °C what is the mass of cementite present?

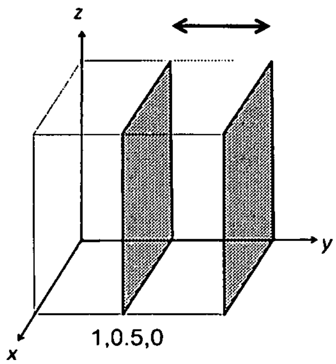
(b) (2 points) For an 1 kg sample of a 0.76 wt%C steel at 728 °C what is the mass of austenite present?

(c) (2 points) For an 1 kg sample of a 5 wt%C cast iron at 1146 °C what is the mass of austenite present?

(d) (2 points) For an 1 kg sample of a 0.5 wt%C steel at 726 °C what is the mass of cementite present?

(e) (2 points) For an 1 kg sample of a 0.3 wt%C steel at 728 °C what is the mass of cementite present?

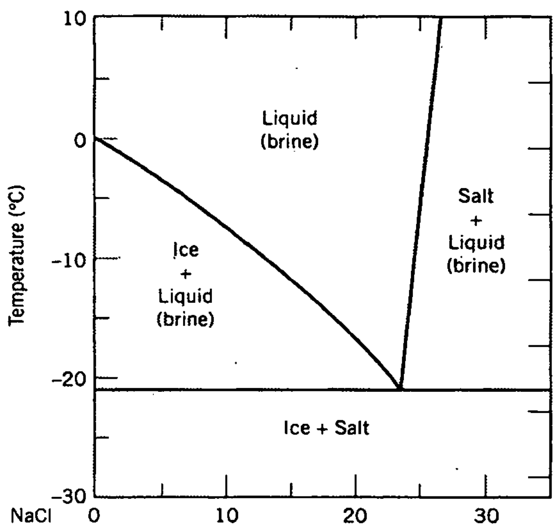
2. (5 points) Making reference to the figure below, and to Bragg's law, explain why peaks in the x-ray diffraction pattern of a BCC crystal would not be expected for the (001) set of planes while they would be expected for the (001) set of planes in a simple cubic metal. Point form answers are acceptable and all of your answer must be written within the space for this question (read: don't write too much).



3. (5 points) An alumina beam having a cross-section of 15 mm in width and 3 mm in height, and a fracture strength in bending of 500 MPa is used to support a 120 g component in a furnace. What is the maximum span that this beam can support such that it is only loaded to half of its fracture strength?

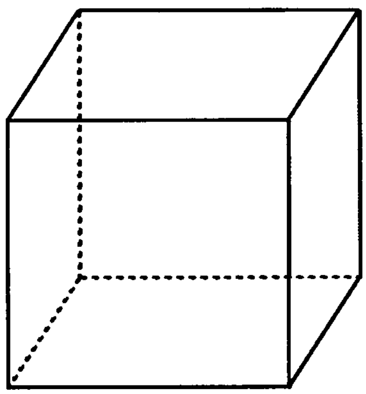
4. (10 points) Pure tin (Sn) at temperatures below 13.2 °C exists in the diamond cubic crystal structure and is known as α tin. If the atomic radius of tin is 139 pm, determine the theoretical density of α tin. Note: 1 pm = 1×10^{-12} m

5. (15 points) Consider 2 g of NaCl at 25 °C added to 98 g of ice at −5 °C, within a well insulated flask (assume isolated system). If all of the salt dissolves, and the system is allowed to reach equilibrium, what will the final temperature of the system be? Start by assuming the system remains at the temperature of the ice and use the phase diagram to determine the mass of ice that is melted, then assume the enthalpies of fusion and dissolution act to change the temperature of the brine plus ice mixture. Assume the heat capacity of dilute brine (salt solution) is equal to that of water.

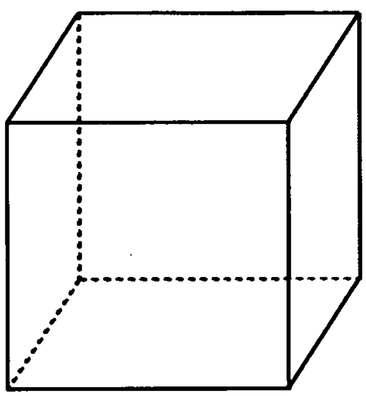


6. Within the unit cells below, sketch the crystallographic directions or planes. In the case of a family of planes or directions, draw all of the members of the family, but don't draw parallel copies of planes.

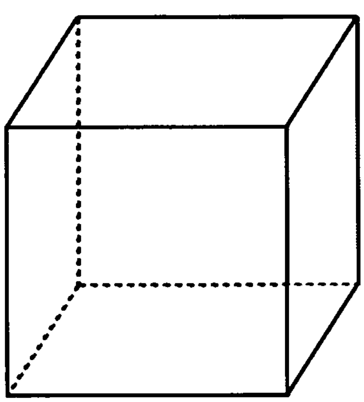
(a) (1 point) $[1\bar{2}0]$



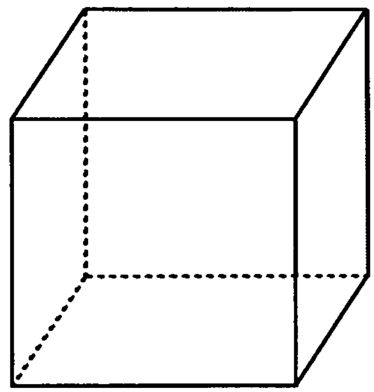
(b) (1 point) $(1\bar{2}0)$



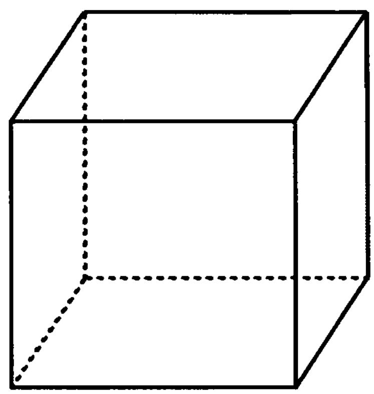
(c) (1 point) $(\bar{1}21)$



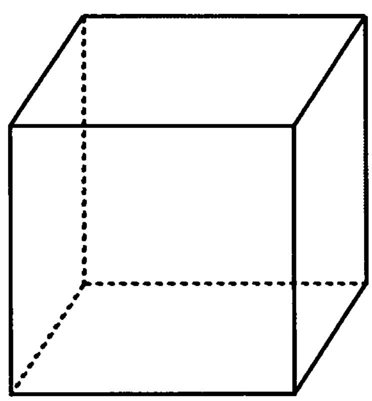
(d) (1 point) $[\bar{2}\bar{2}1]$



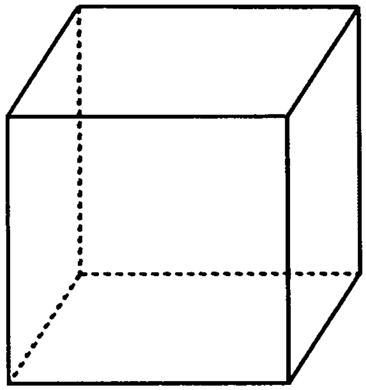
(e) (1 point) $\langle 111 \rangle$



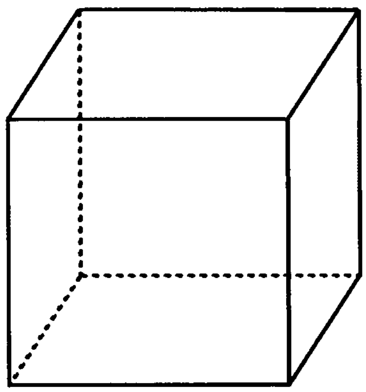
(f) (1 point) 011



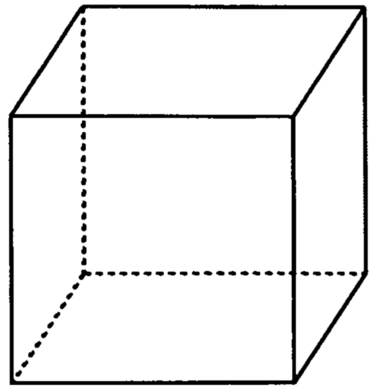
(g) (1 point) $\langle 011 \rangle$



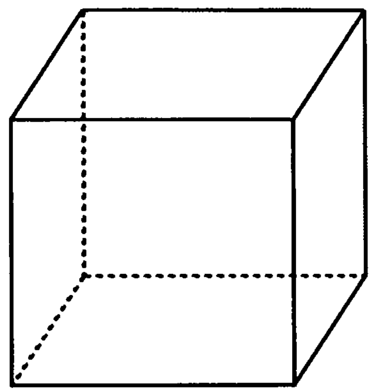
(h) (1 point) $[2\bar{1}0]$



(i) (1 point) $(1\bar{2}1)$



(j) (1 point) $(1\bar{1}1)$



7. Refer to the following data in responding to these questions.

Table 1: Selected semiconductor properties at 300 K.

Semiconductor	$E_g(eV)$	$n_i(m^{-1})$	$\mu_e(\frac{m^2}{V\cdot s})$	$\mu_h(\frac{m^2}{V\cdot s})$
Si	1.10	1.45×10^{16}	0.135	0.045
GaAs	1.42	1.8×10^{12}	0.850	0.040
GaAs	0.66	2.4×10^{19}	0.390	0.190

(a) (3 points) Calculate the intrinsic conductivities of Si and GaAs given the data in the table above. Which has the higher intrinsic conductivity at 300 K, Si or GaAs?

(b) (2 points) What is the doping concentration of boron (B) required to raise the conductivity of Si to $10\,\Omega^{-1}\,m^{-1}$?

(c) (2 points) Express the answer from part b in terms of the number of Si atoms per dopant atom. The lattice constant for Si is 0.543 nm.

8. The saturation magnetization for Ni is $M_{sat} = 4.70 \times 10^5 \frac{A}{m}$. Ni is FCC with an atomic radius of 124 pm

   (a) (3 points) Express the saturation magnetization as the number of Bohr magnetons per atom.

   (b) (2 points) What would be the expected value from the electronic configuration of Ni?

Part B: Multiple Choice (1 points per question)

1. Which of the following statements is true?

   (a) Every (002) plane is also an (001) plane, however every (001) plane is not necessarily an (002) plane.
   (b) Every (001) plane is also an (002) plane, however every (002) plane is not necessarily an (001) plane.
   (c) Neither of these statements are true.

2. A humidifier operates by evaporating liquid water into water vapour in air. Would you expect to pay more to heat your home in the winter if you operate a humidifier?

   (a) Yes, because 41 kj/mol is consumed to evaporate the water.
   (b) No, because 41 kj/mol is contributed to the air during evaporation of the water.
   (c) Yes, but only if the water is boiled with a heating element.
   (d) None of these are correct.

3. A non-metallic material has a band gap of 2.2 eV. In terms of which wavelength of light that passes through the material, which is true?

   (a) The material passes no wavelengths of visible light (opaque)
   (b) None of these.
   (c) The material passes red light but not blue light
   (d) The material passes all wavelengths of visible light
   (e) The material passes blue light but not red light

4. Which of the following would not result, as a general rule, in an increase in the strength of a polymer?

   (a) Carefully heating a polymer to encourage increased crystallization.
   (b) Carefully deforming a thermoplastic polymer at temperatures below the T_g.
   (c) Introducing cross-links between chains.
   (d) Increasing the molecular weight.
   (e) Blending more than one mer unit in to the polymer.

5. If the anions and cations in the rock salt structure were swapped which of the following statements would be true?

   (a) The structure would be unchanged.
   (b) The cations would now occupy tetrahedral interstitial sites.
   (c) None of these are correct.
   (d) The stoichiometry of the structure would be changed.

6. Which of the following statements are correct?

   1. An increase in the average grain diameter of a metal will result in an increase in the yield strength.
   2. The yield strength of a pure metal is generally greater than that of a mixture of two metals.
   3. Performing cold work on a metal will generally decrease the total strain to fracture.
   4. Strain hardening of a metal begins at the ultimate tensile strength and continues until fracture.
   5. Porosity is an example of a three dimensional imperfection that can be used to increase the strength of a metal.

   (a) 4 only
   (b) 3 and 4
   (c) 3 only
   (d) 2, 3, and 4
   (e) All of these are correct.

7. Which of the following statements is most true about silicon doped with Arsenic (As)?

   (a) Electron excitation results in an electron from a level within the band gap being promoted into the conduction band.
   (b) Electron excitation results in an electron being promoted from the valence band to the conduction band.
   (c) Electron excitation results in the generation of a hole within the valence band.
   (d) None of these.
   (e) Electron excitation results in the generation of holes in the conduction band.

8. Adding a high molar mass element to the mer unit of a polymer would be most likely to result in which of the following?

   (a) An increase in the strength of the polymer.
   (b) An increase in the density of the polymer.
   (c) Neither of these are correct.

9. Which of the following statements are true?

   1. An increase in Gibbs energy for a system at constant temperature and pressure corresponds with a spontaneous process.
   2. The first law of thermodynamics introduces the fundamental property of internal energy.
   3. The second law of thermodynamics introduces the fundamental property of the entropy.
   4. The absolute value of the internal energy is not of general interest in thermodynamics.
   5. The absolute value of the entropy cannot be determined.

   (a) 1, and 5 only.
   (b) 2, 3, and 4.
   (c) 1, 2, and 3.
   (d) 3, 4, and 5.

10. Which of the following statements is correct about an indium (In) doped group IV semiconductor?

    1. The band gap of this material would be larger than 4 eV
    2. The band gap of this material would be smaller than 4 eV
    3. This material has no band gap
    4. The conductivity of this material is dominated by the electron mobility
    5. The conductivity of this material is dominated by the hole mobility

    (a) 5
    (b) 2 and 4
    (c) 1 and 4
    (d) 2 and 5
    (e) 3

11. Carbon can dissolve as a point imperfection in BCC iron up a maximum of 0.022 wt%. What happens to carbon added above this composition?

    (a) None of these are correct.
    (b) It reacts with iron to form a three dimensional imperfection.
    (c) It accumulates along dislocation lines.
    (d) It precipitates out of solution as graphite.

12. A mole of ethanol combusted with oxygen within a closed container would be expected to generate more heat than the same reaction proceeding exposed to the atmosphere for which of the following reasons?

    (a) The enthalpy is higher when performed exposed to the atmosphere.
    (b) The statement is incorrect. The heat generated would be the same in both cases.
    (c) Work is used in pushing back the atmosphere.
    (d) Heat is conducted away.

13. Which statements are true for a paramagnetic material?

    (a) It is possible to have permanent magnetization below the Curie temperature.
    (b) Adjacent dipoles have a tendency to align in an anti-parallel fashion.
    (c) All the magnetic dipoles have a tendency to align with an applied field.
    (d) The magnetic susceptibility is weakly negative.
    (e) None of these.

14. In bungee jumping, an bundle of elastomer strands are secured to a human who then jumps off an elevated platform, allowing the human to bounce (somewhat) safely at the end of the bungee cord, without impacting the ground. If a new company advertises a new bungee cord material with an ultra high Young's modulus, would you be reassured or concerned?

    (a) Reassured, because the stresses on the bungee cord would be generally less and so would experience less wear and tear.
    (b) Concerned, because the deceleration may be high and cause injury.
    (c) Concerned, because the elastic elongation may be so high as to allow the human to strike the ground.
    (d) Reassured, because the bungee cord will be less likely to fracture.

15. A crystal structure formed from atoms occupying FCC positions (but not touching along 011 directions), with the same atoms occupying one half of the tetrahedral interstitial sites would be named which of the following?

    (a) Diamond cubic
    (b) Zinc blend
    (c) Rock salt
    (d) Calcium fluorite

16. Which of the following can be determined by referencing a phase diagram, given an overall composition and temperature?

    1. Amount (mass fraction) of phase(s) present.
    2. Rate of formation of a phase.
    3. Composition of phase(s) present.
    4. How many phases are present.
    5. Theoretical density of a phase.

    (a) 1, 3, and 4.
    (b) 1, 2, and 4.
    (c) 3, 4, and 5.
    (d) 2 and 5 only.

17. The ultimate tensile strength is to a metal what which of the following is to a polymer.

    (a) Yield strength
    (b) End of linear elastic region
    (c) Fracture strength.
    (d) Tensile strength

18. An increase in the Gibbs energy of a system is equivalent to which of the following?

    (a) A negative enthalpy change for the system.
    (b) A positive enthalpy change for the system.
    (c) A decrease in the entropy of the universe.
    (d) An increase in the entropy of the universe.

19. The Young's modulus of a pure metal is directly proportional to which of the following?

    (a) The integral of the interatomic force-separation curve from equilibrium spacing to infinity.
    (b) The second derivative of the interatomic force-separation curve.
    (c) The first derivative of the interatomic force-separation curve.
    (d) None of these are correct.

20. What type of bonding is present in GaAs?

    (a) Ionic
    (b) Mixed ionic and covalent
    (c) Metallic
    (d) Covalent

Name: ______________________________ **Student ID Number:** ______________________

Instructions:

Please completely fill in the rectangle associated with your response. Example: ▬ [B] [C] [D] [E]

	A	B	C	D	E		A	B	C	D	E		A	B	C	D	E		A	B	C	D	E
1	[A]	[B]	[C]	[D]	[E]	26	[A]	[B]	[C]	[D]	[E]	51	[A]	[B]	[C]	[D]	[E]	76	[A]	[B]	[C]	[D]	[E]
2	[A]	[B]	[C]	[D]	[E]	27	[A]	[B]	[C]	[D]	[E]	52	[A]	[B]	[C]	[D]	[E]	77	[A]	[B]	[C]	[D]	[E]
3	[A]	[B]	[C]	[D]	[E]	28	[A]	[B]	[C]	[D]	[E]	53	[A]	[B]	[C]	[D]	[E]	78	[A]	[B]	[C]	[D]	[E]
4	[A]	[B]	[C]	[D]	[E]	29	[A]	[B]	[C]	[D]	[E]	54	[A]	[B]	[C]	[D]	[E]	79	[A]	[B]	[C]	[D]	[E]
5	[A]	[B]	[C]	[D]	[E]	30	[A]	[B]	[C]	[D]	[E]	55	[A]	[B]	[C]	[D]	[E]	80	[A]	[B]	[C]	[D]	[E]
6	[A]	[B]	[C]	[D]	[E]	31	[A]	[B]	[C]	[D]	[E]	56	[A]	[B]	[C]	[D]	[E]	81	[A]	[B]	[C]	[D]	[E]
7	[A]	[B]	[C]	[D]	[E]	32	[A]	[B]	[C]	[D]	[E]	57	[A]	[B]	[C]	[D]	[E]	82	[A]	[B]	[C]	[D]	[E]
8	[A]	[B]	[C]	[D]	[E]	33	[A]	[B]	[C]	[D]	[E]	58	[A]	[B]	[C]	[D]	[E]	83	[A]	[B]	[C]	[D]	[E]
9	[A]	[B]	[C]	[D]	[E]	34	[A]	[B]	[C]	[D]	[E]	59	[A]	[B]	[C]	[D]	[E]	84	[A]	[B]	[C]	[D]	[E]
10	[A]	[B]	[C]	[D]	[E]	35	[A]	[B]	[C]	[D]	[E]	60	[A]	[B]	[C]	[D]	[E]	85	[A]	[B]	[C]	[D]	[E]
11	[A]	[B]	[C]	[D]	[E]	36	[A]	[B]	[C]	[D]	[E]	61	[A]	[B]	[C]	[D]	[E]	86	[A]	[B]	[C]	[D]	[E]
12	[A]	[B]	[C]	[D]	[E]	37	[A]	[B]	[C]	[D]	[E]	62	[A]	[B]	[C]	[D]	[E]	87	[A]	[B]	[C]	[D]	[E]
13	[A]	[B]	[C]	[D]	[E]	38	[A]	[B]	[C]	[D]	[E]	63	[A]	[B]	[C]	[D]	[E]	88	[A]	[B]	[C]	[D]	[E]
14	[A]	[B]	[C]	[D]	[E]	39	[A]	[B]	[C]	[D]	[E]	64	[A]	[B]	[C]	[D]	[E]	89	[A]	[B]	[C]	[D]	[E]
15	[A]	[B]	[C]	[D]	[E]	40	[A]	[B]	[C]	[D]	[E]	65	[A]	[B]	[C]	[D]	[E]	90	[A]	[B]	[C]	[D]	[E]
16	[A]	[B]	[C]	[D]	[E]	41	[A]	[B]	[C]	[D]	[E]	66	[A]	[B]	[C]	[D]	[E]	91	[A]	[B]	[C]	[D]	[E]
17	[A]	[B]	[C]	[D]	[E]	42	[A]	[B]	[C]	[D]	[E]	67	[A]	[B]	[C]	[D]	[E]	92	[A]	[B]	[C]	[D]	[E]
18	[A]	[B]	[C]	[D]	[E]	43	[A]	[B]	[C]	[D]	[E]	68	[A]	[B]	[C]	[D]	[E]	93	[A]	[B]	[C]	[D]	[E]
19	[A]	[B]	[C]	[D]	[E]	44	[A]	[B]	[C]	[D]	[E]	69	[A]	[B]	[C]	[D]	[E]	94	[A]	[B]	[C]	[D]	[E]
20	[A]	[B]	[C]	[D]	[E]	45	[A]	[B]	[C]	[D]	[E]	70	[A]	[B]	[C]	[D]	[E]	95	[A]	[B]	[C]	[D]	[E]
21	[A]	[B]	[C]	[D]	[E]	46	[A]	[B]	[C]	[D]	[E]	71	[A]	[B]	[C]	[D]	[E]	96	[A]	[B]	[C]	[D]	[E]
22	[A]	[B]	[C]	[D]	[E]	47	[A]	[B]	[C]	[D]	[E]	72	[A]	[B]	[C]	[D]	[E]	97	[A]	[B]	[C]	[D]	[E]
23	[A]	[B]	[C]	[D]	[E]	48	[A]	[B]	[C]	[D]	[E]	73	[A]	[B]	[C]	[D]	[E]	98	[A]	[B]	[C]	[D]	[E]
24	[A]	[B]	[C]	[D]	[E]	49	[A]	[B]	[C]	[D]	[E]	74	[A]	[B]	[C]	[D]	[E]	99	[A]	[B]	[C]	[D]	[E]
25	[A]	[B]	[C]	[D]	[E]	50	[A]	[B]	[C]	[D]	[E]	75	[A]	[B]	[C]	[D]	[E]	100	[A]	[B]	[C]	[D]	[E]

IUPAC Periodic Table of the Elements

Key:

atomic number **Symbol** name abridged standard atomic weight

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 **H** hydrogen 1.0080 ± 0.0002																	2 **He** helium 4.0026 ± 0.0001
3 **Li** lithium 6.94 ± 0.06	4 **Be** beryllium 9.0122 ± 0.0001											5 **B** boron 10.81 ± 0.02	6 **C** carbon 12.011 ± 0.002	7 **N** nitrogen 14.007 ± 0.001	8 **O** oxygen 15.999 ± 0.001	9 **F** fluorine 18.998 ± 0.001	10 **Ne** neon 20.180 ± 0.001
11 **Na** sodium 22.990 ± 0.001	12 **Mg** magnesium 24.305 ± 0.002											13 **Al** aluminium 26.982 ± 0.001	14 **Si** silicon 28.085 ± 0.001	15 **P** phosphorus 30.974 ± 0.001	16 **S** sulfur 32.06 ± 0.02	17 **Cl** chlorine 35.45 ± 0.01	18 **Ar** argon 39.95 ± 0.16
19 **K** potassium 39.098 ± 0.001	20 **Ca** calcium 40.078 ± 0.004	21 **Sc** scandium 44.956 ± 0.001	22 **Ti** titanium 47.867 ± 0.001	23 **V** vanadium 50.942 ± 0.001	24 **Cr** chromium 51.996 ± 0.001	25 **Mn** manganese 54.938 ± 0.001	26 **Fe** iron 55.845 ± 0.002	27 **Co** cobalt 58.933 ± 0.001	28 **Ni** nickel 58.693 ± 0.001	29 **Cu** copper 63.546 ± 0.003	30 **Zn** zinc 65.38 ± 0.02	31 **Ga** gallium 69.723 ± 0.001	32 **Ge** germanium 72.630 ± 0.008	33 **As** arsenic 74.922 ± 0.001	34 **Se** selenium 78.971 ± 0.008	35 **Br** bromine 79.904 ± 0.003	36 **Kr** krypton 83.798 ± 0.002
37 **Rb** rubidium 85.468 ± 0.001	38 **Sr** strontium 87.62 ± 0.01	39 **Y** yttrium 88.906 ± 0.001	40 **Zr** zirconium 91.224 ± 0.002	41 **Nb** niobium 92.906 ± 0.001	42 **Mo** molybdenum 95.95 ± 0.01	43 **Tc** technetium [97]	44 **Ru** ruthenium 101.07 ± 0.02	45 **Rh** rhodium 102.91 ± 0.01	46 **Pd** palladium 106.42 ± 0.01	47 **Ag** silver 107.87 ± 0.01	48 **Cd** cadmium 112.41 ± 0.01	49 **In** indium 114.82 ± 0.01	50 **Sn** tin 118.71 ± 0.01	51 **Sb** antimony 121.76 ± 0.01	52 **Te** tellurium 127.60 ± 0.03	53 **I** iodine 126.90 ± 0.01	54 **Xe** xenon 131.29 ± 0.01
55 **Cs** caesium 132.91 ± 0.01	56 **Ba** barium 137.33 ± 0.01	57-71 lanthanoids	72 **Hf** hafnium 178.49 ± 0.01	73 **Ta** tantalum 180.95 ± 0.01	74 **W** tungsten 183.84 ± 0.01	75 **Re** rhenium 186.21 ± 0.01	76 **Os** osmium 190.23 ± 0.03	77 **Ir** iridium 192.22 ± 0.01	78 **Pt** platinum 195.08 ± 0.02	79 **Au** gold 196.97 ± 0.01	80 **Hg** mercury 200.59 ± 0.01	81 **Tl** thallium 204.38 ± 0.01	82 **Pb** lead 207.2 ± 1.1	83 **Bi** bismuth 208.98 ± 0.01	84 **Po** polonium [209]	85 **At** astatine [210]	86 **Rn** radon [222]
87 **Fr** francium [223]	88 **Ra** radium [226]	89-103 actinoids	104 **Rf** rutherfordium [267]	105 **Db** dubnium [268]	106 **Sg** seaborgium [269]	107 **Bh** bohrium [270]	108 **Hs** hassium [269]	109 **Mt** meitnerium [277]	110 **Ds** darmstadtium [281]	111 **Rg** roentgenium [282]	112 **Cn** copernicium [285]	113 **Nh** nihonium [286]	114 **Fl** flerovium [290]	115 **Mc** moscovium [290]	116 **Lv** livermorium [293]	117 **Ts** tennessine [294]	118 **Og** oganesson [294]

57 **La** lanthanum 138.91 ± 0.01	58 **Ce** cerium 140.12 ± 0.01	59 **Pr** praseodymium 140.91 ± 0.01	60 **Nd** neodymium 144.24 ± 0.01	61 **Pm** promethium [145]	62 **Sm** samarium 150.36 ± 0.02	63 **Eu** europium 151.96 ± 0.01	64 **Gd** gadolinium 157.25 ± 0.03	65 **Tb** terbium 158.93 ± 0.01	66 **Dy** dysprosium 162.50 ± 0.01	67 **Ho** holmium 164.93 ± 0.01	68 **Er** erbium 167.26 ± 0.01	69 **Tm** thulium 168.93 ± 0.01	70 **Yb** ytterbium 173.05 ± 0.02	71 **Lu** lutetium 174.97 ± 0.01
89 **Ac** actinium [227]	90 **Th** thorium 232.04 ± 0.01	91 **Pa** protactinium 231.04 ± 0.01	92 **U** uranium 238.03 ± 0.01	93 **Np** neptunium [237]	94 **Pu** plutonium [244]	95 **Am** americium [243]	96 **Cm** curium [247]	97 **Bk** berkelium [247]	98 **Cf** californium [251]	99 **Es** einsteinium [252]	100 **Fm** fermium [257]	101 **Md** mendelevium [258]	102 **No** nobelium [259]	103 **Lr** lawrencium [262]

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For notes and updates to this table, see www.iupac.org. This version is dated 4 May 2022.

Constants and conversions

1 atm = 101.325 kPa = 1.013 25 bar = 14.696 psi

N_A	$6.022 \times 10^{23}\,\mathrm{mol^{-1}}$
e	$1.602 \times 10^{-19}\,\mathrm{C}$
1 eV	$1.602 \times 10^{-19}\,\mathrm{J}$
ϵ_0	$8.854 \times 10^{-12}\,\mathrm{F\,m^{-1}}$
R	$8.314\,\mathrm{J\,mol^{-1}\,K^{-1}}$
	$0.082\,067\,\mathrm{L\,atm\,mol^{-1}\,K^{-1}}$
0 °C	273.15 K
k	$8.62 \times 10^{-5}\,\mathrm{eV\,atom^{-1}\,K^{-1}}$
	$1.38 \times 10^{-23}\,\mathrm{J\,atom^{-1}\,K^{-1}}$
F	$96\,486\,\mathrm{°C\,mol^{-1}}$
h	$6.626 \times 10^{-34}\,\mathrm{J\,s}$
	$4.136 \times 10^{-15}\,\mathrm{eV\,s}$
c	$2.99 \times 10^{8}\,\mathrm{m\,s^{-1}}$
g	$9.81\,\mathrm{m\,s^{-2}}$

Microstructure

$LD = \frac{\#}{\text{Length}}$ $\quad LPF = \frac{\text{length of atoms}}{\text{length of vector}}$

$PD = \frac{\#}{\text{Area}}$ $\quad PPF = \frac{\text{area of atoms}}{\text{area of plane}}$

$V = \frac{4}{3}\pi r^3$ $\quad A = \pi r^2$

$A_{\text{triange}} = \frac{1}{2}bh$ $\quad \rho = \frac{nA}{V_C N_A}$

$\rho = \frac{n_A A_A + n_C A_C}{V_C N_A}$ $\quad APF = \frac{V_s}{V_C}$

$N = \frac{N_A \rho}{A}$ $\quad N_V = N \exp(-\frac{Q_V}{kT})$

$a = 2\sqrt{2}R$ $\quad a = \frac{4}{\sqrt{3}}R$

$d_{\text{hkl}} = \frac{a}{\sqrt{h^2+k^2+l^2}}$ $\quad n\lambda = 2d_{\text{hkl}}\sin\theta$

$n_n = \frac{M_n}{m}$ $\quad n_w = \frac{M_w}{m}$

Mechanical Behaviour

$\sigma = \frac{F}{A_0}$ $\quad \epsilon = \frac{\Delta l}{l_0}$

$\sigma = E\epsilon$ $\quad \sigma_{\text{3-point}} = \frac{3FL}{2wh^2}$

$\sigma_T = \sigma(1+\epsilon)$ $\quad \epsilon_T = \ln(1+\epsilon)$

$\sigma_T = \frac{F}{A_i}$ $\quad \sigma_T = K\epsilon_T^n$

$E = 2G(1+\nu)$ $\quad \nu = -\frac{\epsilon_x}{\epsilon_z} = -\frac{\epsilon_y}{\epsilon_z}$

Magnetic Behaviour

$H = \frac{NI}{L}$ $\quad B_0 = \mu_0 H$

$M = \chi_m H$ $\quad B = \mu_0 H + \mu_0 M$

$B = (1+\chi_m)\mu_0 H$ $\quad \mu_B = \frac{e\hbar}{2m_e} = \beta$

$\beta = 9.27 \times 10^{-24} Am^2$

Electrical Behaviour

$\sigma = n|e|\mu_e + p|e|\mu_h$ $\quad \sigma = n|e|\mu_e$

$\sigma = p|e|\mu_h$

Electrochemistry

$E = E^\circ - \frac{RT}{nF}\ln Q$ $\quad I = \frac{nC}{t}$

$E_{\text{at 25 °C}} = E^\circ - \frac{0.0592}{n}\ln Q$

$w = nFE^\circ$

Thermodynamics

$PV = nRT$ $\quad \Delta U = q + w$

$\Delta U = q - P_{\text{ext}}\Delta V$ $\quad H \equiv U + PV$

$G \equiv H - TS$ $\quad \Delta S = \frac{q_{\text{rev}}}{T}$

constant T: $\Delta G = \Delta H - T\Delta S$

$q = mc\Delta T$ $\quad q = nC_P\Delta T$

For $aA + bB \to cC + dD$, $Q = \frac{a_C^c a_D^d}{a_A^a a_B^b}$

$\Delta_r G = \Delta G^\circ + RT\ln Q$

$\Delta_r H^\circ = (\Sigma v_i \Delta_{f,i} H^\circ)_{\text{prod.}} - (\Sigma v_i \Delta_{f,i} H^\circ)_{\text{react.}}$

$\Delta_r S^\circ = (\Sigma v_i \Delta_{f,i} S^\circ)_{\text{prod.}} - (\Sigma v_i \Delta_{f,i} S^\circ)_{\text{react.}}$

$W_{\text{phase}} = \frac{\text{length of opp. side of lever}}{\text{total length of lever}}$

$E = h\nu = \frac{hc}{\lambda}$

Specific heats and heat capacities

Substance	c ($\frac{J}{g \cdot K}$)	C_P ($\frac{J}{mol \cdot K}$)
$CO_{2(g)}$	0.843	37.1
$\text{Air}_{(g)}$	1.0	-
$H_2O_{(g)}$	2.03	36.4
$H_2O_{(l)}$	4.184	75.3
$H_2O_{(s)}$	2.09	37.7
$CO_{2(g)}$	0.843	37.1
$NaCl$	0.853	50.5

Temperatures and enthalpies of phase changes

Substance	M.P. (°C)	$\Delta_{fus}H$ $\frac{kJ}{mol}$	B.P. (°C)	$\Delta_{vap}H$ $\frac{kJ}{mol}$
Al	658	10.6	2467	284
Ca	851	9.33	1487	162
CH_4	-182	0.92	-164	8.18
H_2O	0	6.01	100	40.7
Fe	1530	14.9	2735	354

Standard formation enthalpy, standard entropy and standard formation Gibbs energy at 298.15 K

Species	$\Delta_f H^\circ$ ($\frac{kJ}{mol}$)	S° ($\frac{J}{mol \cdot K}$)	$\Delta_f G^\circ$ ($\frac{kJ}{mol}$)
C	0	5.74	0
$CH_{4(g)}$	-74.81	186.2	-50.75
$C_2H_{2(g)}$	-83.9	200.93	-
$C_3H_{8(g)}$	-103.8	269.9	-23.49
$CaC_{2(s)}$	-59.8	70.3	-
$CaF_{2(s)}$	-1225	68.87	-1162
$CaF_{2(l)}$	-1186	92.6	-
$Ca(OH)_{2(s)}$	-987.0	83.0	-
$CO_{2(g)}$	-393.5	213.6	-394.4
$Cu_2O_{(s)}$	-168.6	93.1	-
$Cu_2O_{(l)}$	-154.79	-	-
$Cu_{(s)}$	-	33.2	-
$Fe_{(s)}$	0	27.3	0
$Fe_2O_{3(s)}$	-824.2	87.4	-
$H_{2(g)}$	-	130.68	-
$H_2O_{(g)}$	-241.8	188.7	-228.6
$H_2O_{(l)}$	-285.8	69	-
$O_{2(g)}$	0	205.0	0

Miscellaneous enthalpies

Substance	Reaction	$\Delta H(\frac{kJ}{mol})$
F-F	Bond dissociation	157
F	$F_{(g)} \to F^-_{(g)}$ Electron affinity	-328
Ca	$Ca_{(g)} \to Ca^{2+}_{(g)}$ 2^{nd} ionization energy	1734
NaCl	$NaCl_{(s)} \to Na^+_{(aq)} + Cl^-_{(aq)}$ Dissolution enthalpy	3.9

Scott Ramsay, April 2023