1. (a) pressure   Pa or N m^{-2} $^{(*)}$
        volume   m^3 $^{(*)}$
        $^{(*)}$ **(1)**(not allow kPa)
        number of moles   mol (or none) **(1)**
        <u>molar</u> gas constant   J K^{-1} mol^{-1} **(1)** (mol^{-1} implies molar)
        temperature   K **(1)**   4

   (b) (i) $\Delta W(= p\Delta V) = 1.0 \times 10^5 \times 5 \times 10^{-5}$ **(1)**
              $= 5.0$ J **(1)**

       (ii) $\dfrac{V}{T}$ = constant (or use of $pV = nRT$) **(1)**

              $\dfrac{1.0 \times 10^{-4}}{293} = \dfrac{1.5 \times 10^{-4}}{T_2}$ **(1)**

              gives $T_2 = 440$K **(1)**
              $= 440 - 273 = 167°$ C **(1)**

       (iii) **any two** from the following:

              speed (or kinetic energy) increases **(1)**
              collision <u>rate</u> (with walls) decreases (or time between
              collisions increases) **(1)**
              distance between collisions increases
              (mean free path inverse prop. to molecular density) **(1)**   8

                                                                                    [12]

2. (a) $pV = nRT$ **(1)**   1

   (b) graph to show:
               straight line **(1)**
               through the origin **(1)**   2

   (c) **average kinetic** energy or speed of the molecules increases
       with temperature **(1)**
       more collisions occur (more frequently) **(1)**
       [or more particles hit (per second)]
       (average) change in momentum (during a collision) is greater **(1)**
       rate of change of momentum is greater **(1)**
       (hence) force/pressure (during collision) is greater **(1)**   max 4
                                                                              QWC 1

(d)   average $E_k = \frac{3}{2}kT$ **(1)**

$= 1.5 \times 1.38 \times 10^{-23} \times 300 = 6.2(1) \times 10^{-21}$ J **(1)**

[or use energy per mole $= \frac{3}{2}RT = \frac{3}{2} \times 8.31 \times 300$

$= 3.74 \times 10^3$ J mol^{-1}]   2

[9]

3. (a) (i)   volume of air is less with the powder present **(1)**
                pressure α 1/volume so pressure is greater **(1)**   QWC 2

        (ii) initial volume $= 3.5 \times 10^{-4}$ (m^3)
              final volume $= 2.5 \times 10^{-4}$ (m^3)

              final pressure $= \dfrac{100 \times 10^3 \times 3.5 \times 10^{-4}}{2.5 \times 10^{-4}}$ **(1)** $= 140 \times 10^3$ Pa **(1)**

              [alternative: no.of moles (n) $(= \dfrac{P_0V_0}{RT_0}) = \dfrac{1.0 \times 10^5 \times 3.5 \times 10^{-4}}{RT_0}$ **(1)** **(1)**

              final pressure $= \dfrac{nRT_0}{V_1} = \dfrac{1.0 \times 10^5 \times 3.5 \times 10^{-4}}{2.5 \times 10^{-4}}$ **(1)** $= 140$ kPa **(1)**   6

    (b) (i)   volume of powder $= \left(\dfrac{\text{mass}}{\text{density}} = \dfrac{0.13}{2700} \right) = 4.8 \times 10^{-5}$ m^3

        (ii) assuming powder volume as in (b)(i),
              initial volume $= (3.5 - 0.48) \times 10^{-4}$ (m^3) **(1)**
              final volume $= (2.5 - 0.48) \times 10^{-4}$ (m^3) **(1)**

              final pressure $= \dfrac{100 \times 10^3 \times 3}{2} = 150 \times 10^3$ Pa **(1)**

              test successful as calculated final pressure = measured final pressure **(1)**   5

[11]

4. (a) (i)   (use of $n = \dfrac{pV}{RT}$ gives) $n = \dfrac{1.0 \times 10^5 \times 1.0}{8.31 \times 300}$ **(1)**

                $= 40(.1)$ moles **(1)**

        (ii) $n = \dfrac{2.2 \times 10^4 \times 1.0}{8.31 \times 270} = 9.8(1)$ moles **(1)**   3

(b) (total) = $(40 \times 6 \times 10^{23}) - (9.8 \times 6 \times 10^{23}) = 1.8(1) \times 10^{25}$ **(1)**

(allow C.E. for incorrect values of *n* from (a))

(oxygen molecules) = $0.23 \times 1.8 \times 10^{25} = 4.2 \times 10^{24}$ **(1)**　　　　　　2

[5]

5.　(a)　use *of pV* = constant or $p_1V_1 = p_2V_2$ **(1)**

$p = 99 \times 3.50/4.15$ **(1)**

= 83.5 kPa **(1)**　　　　　　3

(b)　no. of moles = $99 \ [\times \ 10] \times 3.5 \times 10^{-4}/8.31 \times$ **291 (1)**

= $1.4(3) \times 10^{-2}$ moles **(1)**

no. of molecules (= $1.4(3) \times 10^{-2} \times 6.02 \times 10^{-23}$)

= $8.6(1) \times 10^{-21}$ **(1)**　　　　　　3

(c)　molecules/particles have momentum **(1)**

momentum change at wall **(1)**

momentum change at wall/collision at wall leads to force **(1)**
[allow impulse arguments]

less air so fewer molecules **(1)**

so change in momentum per second/rate of change is less
[*or* per unit per time] **(1)**

pressure is proportional to number of molecules (per unit volume) **(1)**　　max 5

[11]

6.　(a)　energy produced　per minute = $4.5 \times 10^3 \times 60$ (J)　**(1)**　$(= 2.7 \times 10^5)$

volume of gas required = $\dfrac{2.7 \times 10^5}{39 \times 10^6}$ (m^3)　**(1)**　$(= 6.9 \times 10^{-3}$ m$^3)$

[or volume of gas per sec $\left(= \dfrac{4500}{39 \times 10^6} \right) = 1.15 \times 10^{-4}$ (m^3)　**(1)**

volume of gas per minute = $1.15 \times 10^{-4} \times 60$ (m^3)　**(1)**$(= 6.9 \times 10^{-3}$ m$^3)$]　　　2

(b)　(i)　$\left(\rho = \dfrac{m}{V} \text{ gives} \right)$　$m_{(g)} = 6.9 \times 10^{-3} \times 0.72$　**(1)**

= 5.0×10^{-3} kg　**(1)**

(ii)　mass of one molecule = $\dfrac{1.6 \times 10^{-2}}{N_A}$　**(1)** $(= 2.66 \times 10^{-26}$ kg)

$$\text{number of molecules} = \left(\frac{5.0 \times 10^{-3}}{2.66 \times 10^{-26}} \right) = 1.9 \times 10^{23} \quad \textbf{(1)}$$

(allow C.E. for value of m_g)

$$[\text{or number of moles} \left(= \frac{5 \times 10^{-3}}{1.6 \times 10^{-2}} \right) = 0.31 \quad \textbf{(1)}$$

number of molecules ($= 0.31 \times 6 \times 10^{23}$) $= 1.9 \times 10^{23}$ **(1)**
(allow C.E. for number of moles) 4

(c) energy per minute (from (a)) $= 2.7 \times 10^5$ (J) **(1)**

$$(\text{use of } \Delta Q = mc\Delta\theta \text{ gives}) \quad m \, (= \frac{\Delta Q}{c\Delta\theta}) = \frac{2.7 \times 10^5}{990 \times (36 - 14)} \quad \textbf{(1)}$$

$= 12(.4) \text{ kg}$ **(1)**

$$[\text{or } m = \frac{4500}{990 \times (36 - 14)} \text{ for 1 second} \quad \textbf{(1)} \quad = 0.21 \text{ (kg for 1 second)} \quad \textbf{(1)}$$

$(= 0.21 \times 60) = 12 \text{ kg for 1 minute}$ **(1)**] 3

(d) $$(\text{use of } P = IV \text{ gives}) \quad I \left(= \frac{P}{V} = \frac{4.5 \times 10^3}{230} \right) = 19(.6) \text{ A} \quad \textbf{(1)}$$

current required for 4.5 kW would exceed fuse rating
[or P = 3 kW for 13 A] **(1)** 2

[11]

7. (a) (i) thermal energy gained by water $= 0.45 \times 4200 \times (35 - 15)$
$= 3.78 \times 10^4$ J **(1)**

(ii) (thermal energy loss by copper = thermal energy gained by water gives)

$0.12 \times 390 \times \Delta T = 3.78 \times 10^4$ **(1)**

$$\Delta T = \frac{3.78 \times 10^4}{0.12 \times 390} = 808 \text{ K}$$

flame temperature ($= 808 + 35°C$) $= 843°C$ or 1116 K **(1)** 3

(b) (i) measure the total mass of the water, beaker and iron lump (to find the mass of water lost) **(1)**

mass of water lost due to conversion to steam, m = mass measured in (b) (i) - initial mass of water, beaker and iron **(1)**

add the thermal energy due to steam produced, mL, to the thermal energy gained by the water **(1)**

calculated flame temperature would be greater **(1)**   4

[7]

8. (a) (i) (use of $pV = nRT$ gives) $n = \dfrac{1.0 \times 10^5 \times 5.0 \times 10^{-3}}{8.31 \times 310}$ **(1)**

=0.194 moles **(1)**

(ii) average kinetic energy = $^3/_2 \times 1.38 \times 10^{-23} \times 310$ **(1)**

$= 6.4 \times 10^{-21}$J **(1)**   4

(b) same temperature **(1)**
(hence) same **average** kinetic energy **(1)**
(since) kinetic energy is $\frac{1}{2}mv^2$ **(1)**
nitrogen **molecules** must have a higher mean square speed **(1)**   3

[7]

9. (a) (i) $pV = nRT$ **(1)**

(ii) all particles identical or have same mass **(1)**
collisions of gas molecules are elastic **(1)**
inter molecular forces are negligible (except during collisions) **(1)**
volume of molecules is negligible (compared to volume of container) **(1)**
time of collisions is negligible **(1)**
motion of molecules is random **(1)**
large number of molecules present
                  (therefore statistical analysis applies) **(1)**
monamatic gas **(1)**
Newtonian mechanics applies **(1)**   max 4

(b) $E_k = \dfrac{3RT}{2N_A}$ or $\dfrac{3}{2}kT$ **(1)**

       $= \dfrac{3 \times 8.31 \times 293}{2 \times 6.02 \times 10^{23}}$ **(1)**

       $= 6.1 \times 10^{-21}$ J **(1)** $(6.07 \times 10^{-21}$ J)   3

(c)   masses are different **(1)**
       hence because E_k is the same, mean square speeds must be different **(1)**   2

                                                                                             [9]

10. (a) (i)   no net flow of (thermal) energy (between two or more bodies) **(1)**
                 bodies at same temperature **(1)**

         (ii) (kinetic) energy is exchanged in molecular collisions **(1)**
                until average kinetic energy of all molecules is the same **(1)**   max 3

(b) (i) $c_{\text{r.m.s.}} \left(= \sqrt{\dfrac{3RT}{M}}\right) = \sqrt{\dfrac{3 \times 8.31 \times 290}{4.00 \times 10^{-3}}}$ **(1)**

               $= 1340$m s^{-1} **(1)**

         (ii) average k.e. of nitrogen molecules = average k.e. of helium
                molecules **(1)**

               $= \dfrac{1}{2} \times \dfrac{4.00 \times 10^{-3}}{6.02 \times 10^{23}} (1340)^2 = 5.97 \times 10^{-21}$ J **(1)**

               alternative schemes for (ii):

               average k.e. $= \dfrac{3}{2}kT$ **(1)**

                      $= \dfrac{3}{2} \times 1.38 \times 10^{-23} \times 290$

                      $= 6.00 \times 10^{-21}$ J **(1)**

or

$$\text{average k.e.} = \frac{3}{2} \frac{RT}{N_A} \textbf{ (1)}$$

$$= \frac{3}{2} \times \frac{8.31 \times 290}{6.02 \times 10^{23}}$$

$$= 6.00 \times 10^{-21} \text{ J } \textbf{(1)}$$

    (iii)   use of $p = \dfrac{nkT}{V}$ or equivalent [or, at same temperature,

            $p \propto$ no. of molecules] **(1)**

            $p_{\text{He}} = \dfrac{2}{3} \times 120 = 80$ kPa **(1)**   6

[9]

11.   (a)   curve A below original, curve B above original **(1)**
            both curves correct shape **(1)**   2

    (b)   (i)   (use of $pV = nRT$ gives) $130 \times 10^3 \times 0.20 = n \times 8.31 \times 290$ **(1)**
                 $n = 11$ (mol) **(1)** (10.8 mol)

         (ii)   (use of $E_k = \frac{3}{2} kT$ gives) $E_k = \frac{3}{2} \times 1.38 \times 10^{-23} \times 290$ **(1)**
                $= 6.0 \times 10^{-21}$ J **(1)**

         (iii)   (no. of molecules) $N = 6.02 \times 10^{23} \times 10.8$ (= 6.5×10^{24})
               total k.e. = $6.5 \times 10^{24} \times 6.0 \times 10^{-21} = 3.9 \times 10^4$ J **(1)**
               (allow C.E. for value of n and E_k from (i) and (ii))
               (use of $n = 11$ (mol) gives total k.e. = 3.9 (7) $\times 10^4$ J)   5

[7]

12.   (a)   (i)   a collision in which kinetic energy is conserved **(1)**

(ii)   molecules of a gas are identical
[or all molecules have the same mass] **(1)**
molecules exert no forces on each other except during impact **(1)**
motion of molecules is random
[or molecules move in random directions] **(1)**

volume of molecules is negligible (compared to volume of container)
[or very small compared to volume of container or point particles] **(1)**
time of collision is negligible (compared to time between collisions) **(1)**
Newton's laws apply **(1)**
large number of particles **(1)**   (any two)   3

(b)   (i)   the hot gas cools and cooler gas heats up
until they are at same temperature
hydrogen molecules transfer energy to oxygen molecules
until **average k.e.** is the same
(any two **(1) (1)**)

(ii)   (use of $E_k = \dfrac{3}{2}kT$ gives) $E_k = \dfrac{3}{2} \times 1.38 \times 10^{-23} \times 420$ **(1)**

$= 8.7 \times 10^{-21}$ J $(8.69 \times 10^{-21}$ J$)$ 4

[7]

13.   (a) $p_1V_1 = p_2V_2$ **(1)**
$1.01 \times 10^5 \times (30.0 + V) = 1.74 \times 10^5\ V$ **(1)**
$V = 41.5$ cm^3 **(1)**

(b)   rapid compression gives little time for heat to leave canister **(1)**
adiabatic process **(1)**
air temperature rises **(1)**
heat is lost **(1)**
temperature (and pressure) fall **(1)**

[Max 5]

14.   (a)   (i) $T (= 273 + 22) = 295$ (K)   **(1)**

         (ii) $pV = nRT$ **(1)**
                $105 \times 10^3 \times 27 = n \times 8.31 \times 295$ **(1)**
                $n = 1160$ (moles)   **(1)**   (1156 moles)
                    (allow C.E. for T (in K) from (i)

         (iii) $N = 1156 \times 6.02 \times 10^{23} = 7.0 \times 10^{26}$ **(1)**   (6.96×10^{26})   5

   (b)   (i)   decreases   **(1)**
              because temperature depends on mean square speed (or $\overline{c^2}$)
              [or depends on mean E_k]   **(1)**

         (ii)   decreases   **(1)**
                as number of collisions (per second) falls   **(1)**
                rate of change of momentum decreases   **(1)**

                [or if using $pV = nRT$
                    decreases   **(1)**
                    as V constant   **(1)**
                    as n constant   **(1)**]
                [or if using $p = 1/3\rho\overline{c^2}$
                    decrease   **(1)**
                    as ρ is constant   **(1)**
                    as $\overline{c^2}$ is constant   **(1)**]   max 4

                                                                                        [9]

15.   (a) p: pressure <u>and</u> V: volume   **(1)**
              N: number of molecules   **(1)**
              m: mass of one molecule/particle/atom   **(1)**
              $\overline{c^2}$: mean square speed   **(1)**   4

   (b)   (i)   molecules have a range of speeds   **(1)**
              they have no preferred direction of movement   **(1)**

         (ii)   elastic collisions
                intermolecular forces are negligible (except during collisions)
                volume of molecules negligible (compared to volume of container)
                time of collisions negligible (compared to time between
                collisions)
                all molecules identical
                laws of statistics apply or large number of molecules
                Newtonian laws apply
                any two   **(1) (1)**   max 3

(c)   molecules collide (with the walls) **(1)**
      walls exert a force on the molecules **(1)**
      molecules exert an (equal) force (on the walls) **(1)**
      creating pressure **(1)**
      molecule momentum changes   max 4

                                                                                        [11]

16. (a) (i) $pV = nRT$ **(1)**

$V = \dfrac{15 \times 8.31 \times 290}{500 \times 10^{3}}$ **(1)** (gives $V = 7.2 \times 10^{-2} \text{m}^3$)

(ii) (use of $E_k = \dfrac{3}{2} kT$ gives) $E_k = \dfrac{3}{2} \times 1.38 \times 10^{-23} \times 290$ **(1)**

$= 6.0 \times 10^{-21}$ (J) **(1)**   4

(b) (use of $pV = nRT$ gives) $n = \dfrac{420 \times 10^{3} \times 7.2 \times 10^{-2}}{8.31 \times 290}$ **(1)**

[or use $p \propto n$]
$n = 13$ moles **(1)** (12.5 moles)   2

(c) pressure is due to molecular bombardment [or moving molecules] **(1)**
     when gas is removed there are fewer molecules in the cylinder
                                            [or density decreases] **(1)**

     (rate of) bombardment decreases **(1)**
     molecules exert forces on wall **(1)**

     $\overline{c^2}$ is constant **(1)**

        [or $pV = \dfrac{1}{3} Nm\langle c^2 \rangle$ **(1)**

        V and m constant **(1)**
        $\langle c^2 \rangle$ constant since T constant **(1)**
        $p \propto N$ **(1)**]
        [or $p = \dfrac{1}{3} \rho \langle c^2 \rangle$ **(1)**

        explanation of ρ decreasing **(1)**]
        $\langle c^2 \rangle$ constant since T constant **(1)**
        $p \propto \rho$ **(1)**]   max 4

                                                                                        [10]

17. (a) (i) more collisions (with wall) per second **(1)**
              and more momentum change per collision **(1)**
              greater force because more momentum change per

second (greater pressure) **(1)**

(ii)   (same pressure) faster molecules so more momentum change
        per collision **(1)**
        greater volume, fewer collisions per second [or greater volume
        to maintain same pressure] **(1)**   max 4

(b)   (i) $V = \left(\dfrac{nRT}{p}\right) = \dfrac{0.250 \times 8.31 \times 300}{1.05 \times 10^5}$ **(1)** $= 5.94 \times 10^{-3}\,\text{m}^3$ **(1)**

(ii) $T_2 = \left(\dfrac{T_1 V_2 p_2}{p_1 V_1}\right) = \dfrac{300 \times 7.0 \times 10^6}{1.05 \times 10^5 \times 20}$

$\left[or\, T_2 = \left(\dfrac{p_2 V_2}{nR}\right) = \dfrac{7.0 \times 10^6 \times 5.94 \times 10^{-3}}{8.31 \times 0.25 \times 20} \right]$ **(1)**

$= 1000\,\text{K}\ (727\,°\text{C})$ **(1)**   4

[8]

18.   (a)   (i)   correct p and V from graph **(1)**

$n = \dfrac{8.00 \times 10^4 \times 2.00 \times 10^{-3}}{8.31 \times 300}$ **(1)** $(= 0.064\ \text{mol})$

(ii) $V_2 = V_1 \dfrac{T_2}{T_1} = 3.3 \times 10^{-3}\,\text{m}^3$ **(1)**   3

(b)   (i) $\dfrac{3}{2} RT$ or $\dfrac{3}{2} N_A kT$ **(1)**

(ii)   total kinetic energy $\left(= \dfrac{3}{2} nRT \right)$

$= 1.5 \times 8.3 \times 0.064 \times 300$ **(1)** $= 239\,\text{J}$ **(1)**
molecules have no potential energy **(1)**
no attractive forces [or elastic collisions occur] **(1)**   max 4

(c) ΔQ = heat entering (or leaving) gas
ΔU = change (or increase) in internal energy
ΔW = work done
[**(1) (1)** for three definitions, deduct one for each incorrect or missing]

(i) $\Delta Q = \Delta U$ **(1)**
       temperature rises but no work done **(1)**

(ii) $\Delta Q = \Delta U + \Delta W$ **(1)**
       temperature rises and work done in expanding **(1)**   max 5

(d) (i) $\Delta U = \dfrac{3}{2} nR(500 - 300) = 159$ J **(1)** $(= \Delta Q)$

     (ii) $p\Delta V = 8.0 \times 10^4 \times (3.3 - 2.0) \times 10^{-3} = 104$ J **(1)**
            $\therefore \Delta Q = \Delta U + p\Delta V = 263$ J **(1)**   3

                                                                                              [15]

19. (a) (i)   pressure **(1)**

          (ii) (average) kinetic energy
                [or rms speed] **(1)**   2

     (b) (i) $pV = nRT$ **(1)**

                $n = \dfrac{1.0 \times 10^{-2} \times 300 \times 10^3}{8.31 \times 290}$ **(1)**

                $= 1.20$(mol) **(1)**   (1.24 mol)

          (ii) mass of air $= 1.24 \times 29 \times 10^{-3} = 0.036$ kg **(1)**
                (allow e.c.f from(i))

          (iii) $\rho = \dfrac{0.0360}{1 \times 10^{-2}} = 3.6$ kg m^{-3} (allow e.c.f. from(ii))   5

     (c) (i)   same **(1)**
                because the temperature is the same **(1)**   QWC

          (ii) different **(1)**
                because the mass of the molecules are different **(1)**   4

                                                                                              [11]