M1. (a) from natural gas [*allow from water/ steam / brine / river / lake / sea*]

for 1 mark

1

(b) *idea that* they are recycled / re-used

for 1 mark

1

(c) *ideas that*

- nitrates may get into ground water / rivers
- so contaminate / get into our drinking water
- eating animals which have eaten crop/ or eating contaminated fish

[do not allow 'eutrophication']

any two for 1 mark each

2

(d) (i) *idea that*
when rate of forward = rate of reverse reaction
[<u>not</u> just 'reversible' or 'can be reversed']
[allow ammonia is breaking up into nitrogen and hydrogen as fast as nitrogen and hydrogen are forming ammonia
<u>or</u> amounts of products and reactants stay constant*]*

for 1 mark

1

(ii) *ideas that*

- at higher temperatures, equilibrium moves to **the** left **or** reverse / endothermic
- reaction / favoured **or** makes products → reactants
- but at lower temperatures the (rate of) reaction is (very) slow
- so a higher temperature is used for economic reasons/so ammonia is produced at higher rate
- iron powder is a catalyst / speeds up the reaction

[<u>not</u> increases the yield]

- low yield not wasteful if reactants re-cycled

[<u>credit</u> iron powder has a greater surface area]

each for 1 mark

4

[9]

##

(a) rate of reaction is increased
iron/powder
acts as catalyst
at higher temperatures
at higher pressures
any 4 answers for 1 mark each

4

(b) yield of ammonia is increased at higher pressure
since equilibrium is moved to the right (idea)
but there is high cost in manufacturing the plant to withstand very high pressures
so optimum* pressure of about 250 atmospheres is used
(– just quoting the figures not enough)*
very high pressure increases safety risk
yield of ammonia is increased at lower temperatures
since equilibrium is moved to the right
but the rate of reaction is reduced at lower temperatures
so process becomes uneconomic
optimum temperature of about 450°C is used
yield of ammonia is increased if the ammonia is removed from the reaction mixture

since equilibrium is moved to the right (idea)
so ammonia is removed as a liquid after cooling and condensing
unreacted nitrogen and hydrogen recycled

(credit nitrogen and ammonia because of misprint on the diagram)

NB Answers in (b) must clearly relate to yield not to rate
(except for the qualification w.r.t. temperature)
any 7 points for 1 mark each

7

[11]

##

(a) $N_2 + \mathbf{3}\ H_2 \leftrightarrow \mathbf{2}\ NH_3$

2

(b) (i) lower temperature gives higher % conversion
higher pressure gives higher % conversion
each for 1 mark

2

(for T = 350 °C and P = 400 At. award 2 marks)

the most economical combination
reaction too slow at lower temperatures
plant too expensive at higher pressures
any 2 for 1 mark each

2

[6]

M4. (a) (i) atmosphere

or (fractional distillation of liquid) air

1

(ii) **either**

more (chance) of them colliding/

not just 'faster'

coming into contact

or

the volume of the product / the ammonia is less than /
only half the volume of the reactants / the nitrogen and hydrogen

1

(iii) 3 × (1 ×2) of hydrogen
→ 2 × (14 +1 ×3) of ammonia

*accept 6 parts of hydrogen →34 parts of ammonia **or** similar*

i.e. candidate uses the atomic masses and works correctly from the equation

1

= 225 (tonnes/t)

unit not required

1

(b) (i) megapascal(s)

accept million pascal(s)

1

(ii) 28 (%)

accept any answer in the range 28.0 to 28.5 inclusive

1

(iii) reduce the temperature and increase the pressure

both required

1

(iv) **either**

use a catalyst

accept use iron as a catalyst

accept use iron which has been more finely divided

accept use iron / catalyst with a bigger (surface) area

accept use a better catalyst

1

or

remove the ammonia (as it is produced)

*accept react the ammonia with **or** dissolve the ammonia in water (as it is produced)*

1

(c) ammonia
nitric acid
phosphoric acid

all three on the left correct

ammonia potassium chloride

all three on the right correct

water **or** water vapour

accept 'steam'

1

[10]

M5. (a) (i) gas

accept they are all gases

1

(ii) reversible (reaction)

accept can go either way
accept ammonia can be decomposed (to nitrogen and hydrogen)
accept could be (an) equilibrium
do not credit just 'equilibrium'

1

(iii) (liquid) air **or** atmosphere

1

(iv) same number **or** amount **or** weight (of atoms) on each side (of the equation)

accept "sums" for each side

accept same amounts of elements on each side
*do not credit molecules **or** compounds*
do not credit both sides are the same unless explained

1

of the same type

***or** gives a correct example 'e.g. six hydrogen atoms' (on each side)*

1

(b) (i) nitrate **or** sulphate **or** phosphate

if first left blank, second may be awarded

do not credit chloride

nitric **or** sulphuric **or** phosphoric

1

(only if correct above, exception is for ammonium chloride followed by hydrochloric acid (1 mark))

as appropriate if only the formula is given this should be credited only if it is correct in every detail i.e. NH_4NO_3 HNO_3 $(NH_4)_2SO_4$ H_2SO_4

accept correct name with an incorrect version of the formula
do not credit a correct formula with an incorrect version of the name e.g. 'nitrate/sulphite' etc

1

any **one** of

* (solution) can be sprayed (on the fields **or** crops)

accept more even distribution

* dissolves in soil water **or** rain (water)

accept soaks into soil (because soaks implies water)

* can be taken up by (plant) roots

do not credit can be added to water to "feed" the plants

1

(c) (i) elements **or** different atoms are bonded or joined **or** combined **or** reacted

do not credit just 'atoms'

*do not credit added **or** mixed*

1

(ii) (pairs of) electrons are shared

do not credit an electron is shared

1

[10]

M6. (a) (i) both scales (must be sensible) (use at least half the paper)
plots for 350°C (to accuracy of +/- 1/2 square)
plots for 500°C (to accuracy of +/- 1/2 square)
lines of best fit (sensible smooth curves) (ignore below 50 atm.)
(must not join the dots and each curve must be a single line)

for 1 mark each

4

(ii) read accurately from their graph (must be 350 °C and pressure read to +/– half square from their graph)

for one mark

1

(iii) smooth curve drawn between 350°C and 500 °C - must be of similar shape to the other curves - a dashed line would be accepted here but would not be accepted for part (i)

for one mark

1

(b) (i) reversible reaction (owtte) / equilibrium / equilibria / reaction goes in both directions etc.

for one mark

1

(ii) maximum of 2 marks from each section up to a maximum total of 5

<u>effect of temperature (max. 2 marks)</u>
best yield at low temperature / poor yield at high temperature
reaction too slow at low temperature / fast at high temperature

<u>effect of pressure (max. 2 marks)</u>
high yield at high pressure (owtte) / low yield at low pressure
ideas to do with cost / safety factor of using higher pressures

<u>evaluation (max. 2 marks)</u>
formation of ammonia favoured at low temperature **because** reaction is exothermic formation of ammonia favoured at high pressure **because** more reactant molecules than product molecules
actual temperature and / or pressure used are a compromise between good yield and reasonable rate ammonia removed / unreacted nitrogen and hydrogen recycled so rate more important than yield catalyst used (not a wrongly named catalyst)

for 1 mark each

5

(c) (i) NH_4NO_3 = 14 + (4 × 1) + 14 + (3 × 16) = 80 (ignore units)

for one mark

1

(ii) ecf (error carried forward from part (i))
look for (28/80) for first mark

gains 1 mark

but 35% (% sign not needed)

special case of (14/80 × 100 = 17.5%) gains one mark

gains 2 marks

2

[15]

M7. (a) (i) A = air
B = natural gas / methane / north sea gas / CH_4 / oil / naphtha/ steam water (H_2O)

Accept answers written in the box at the start of the question.

each for 1 mark

2

(ii) catalyst / speed up the reaction / lower the activation energy

for 1 mark

1

(b) (i) 3 2

for 1 mark

1

(ii) reversible reaction

so that amount of product depends on conditions used

(linked to first point)

best yield at low temperatures

because it is an exothermic reaction / gives out heat (linked)

reaction rate too slow at low temperatures

450 °C is a compromise between a reasonable yield of ammonia at a fast rate of reaction

catalyst works best when heated

best yield at high pressures

because there is a decrease in the number of gaseous molecules (linked)

increasing the pressure also increases the rate

the pressure used is limited by cost, safety etc

the fact that all the nitrogen and hydrogen are not converted to ammonia does not matter because unreacted gases can be recycled through process

any six for 1 mark each

6

[10]

M8. Effect of pressure

- high pressure increases yield

  for 1 mark

- either because less product molecules (Le Chatelier)
  or but high pressure increases cost/safety

  for 1 mark

Effect of temperature

- low temperature increases yield
  for 1 mark
- either because exothermic reaction (Le Chatelier)
  for 1 mark
- or but at low temperature rate is slow/catalyst does not work

Compromise

- optimum conditions to balance rate and % yield
  for 1 mark
- or rate is slow (at higher temperature) so need a catalyst
  or low percentage conversion so recycle untreated gases

[5]

M9. (a) 16%

for 2 marks

(attempt by drawing lines etc gains 1 mark)

2

(b) iron is a catalyst;
which speeds up the reaction

for 1 mark each

2

(c) (from the graph) the best **yield** is obtained at high pressure;
and low temperature;
it is a reversible reaction;
in which formation of ammonia is favoured at low temperature
(because) the reaction is exothermic;
and the formation of ammonia is favoured at high pressure
because greater number of gaseous reactant molecules than
gaseous product molecules/because greater vol of reactant
than volume of product molecules;
pressure used is limited by cost/materials;
rate of reaction slow at low temperatures;
actual temperature and pressure used is a good compromise
(between a good yield and reasonable rate);
removal of ammonia makes rate more important than yield;

any 8 for 1 mark each

8

[12]

M10. (a) (i) 78-80%

1

(ii) proteins

accept amino acids

1

(b) (i) natural gas

accept methane (CH_4)

accept water (H_2O)

1

(ii) carbon dioxide

1

(c) (i) $N_2 + H_2$

1

correct balancing $1 + 3 \rightarrow 2$

award only if reactants are correct

1

(ii) iron

accept Fe

1

(iii) at low temperatures rate of reaction is too slow

accept very few collisions at low temperatures

accept converse

particles need enough (activation) energy to react

accept particles need enough energy for bonds to break

accept converse

1

(d) all three covalent bonds displayed correctly as electron pairs

1

two lone electrons displayed not necessarily as a pair

1

[11]

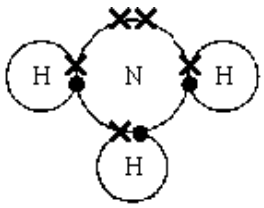
M11. (i) reversible (reaction)

1

(ii) (yield of ammonia) increases

1

(iii)



1

[3]

M12. (a) (i) yield increases

two marks are linked

1

because more (gaseous) reactant molecules / particles than (gaseous) product molecules / particles

accept 7 → 4 moles or volumes
ignore more reactants
accept fewer particles on the right

1

(ii) increased (rate) / faster / speeds up etc

two marks are linked

1

more collisions **or** increased concentration **or** particles closer together

greater chance of more successful collisions

1

(b) heat / high temperatures

*do **not** accept burn it ignore cracking / catalyst*

1

[5]

M13. (a) ***2** marks for comments related to temperature*

low / lower / lowest temperature (**or** 100 °C from graph)

ignore references to catalyst

1

any **one** from:

- (forward) reaction exothermic

  ***or** reverse reaction endothermic*

- if the temperature is increased the yield of product will decrease **or** reaction right to left

  *high temperature favours reverse reaction **or** reverse argument*

  *the lower the temperature the greater the yield = **2** marks*

  ***2** marks for comments related to pressure*

1

high / higher / highest pressure (or greater than 200 atm. from graph)

1

any **one** from:

- four reactant molecules but only two product molecules (owtte)

  reverse reaction goes from 2 molecules / moles / volumes to 4 molecules / moles / volumes

- increase in pressure favours the reaction which produces the least number of molecules

  decrease in pressure favours the back reaction because it produces the most molecules

1

(b) any **three** from:

- at low temperatures the reaction is too slow
- 450 °C gives a reasonable yield at a fast rate / compromise between yield and rate (*)
- 200 atm. gives a reasonable yield at a reasonable cost / safely / compromise between yield and cost / safety (*)

  *(*) or 450°C and 200 atm / these are compromise conditions for **1** mark*

- catalyst works better at higher temperature
- (very) high pressures could be dangerous (owtte)

  safety factor

- (very) high pressures are expensive (owtte)
- (yield is not too important because) unreacted gases can be recycled

3

[7]

M14. (a) (i) high temperature

accept temperature given if ≥ 400 °C
ignore value if "high" stated, unless silly value

1

endothermic or reaction takes in energy
or Δ H is +ve

independent marks

1

(ii) low pressure

or up to and including 10 atmospheres

1

(low pressure) favours a reaction in which more molecules are formed

2 moles → 4 moles
(2 molecules → 4 molecules)

independent marks

1

(iii) nickel **and** it is a transition / transitional element / metal (owtte) **or** nickel **and** variable oxidation state / number or it is similar to other named transition elements e.g. iron

1

(b) (i) (bonds broken =) 2005 (kJ)

1

(bonds formed =) 2046 (kJ)

1

energy change = 2005 – 2046 = (–)41

for correct subtraction ignore sign

1

(ii) (exothermic)

if in part (b)(i) answer is not 41
answer is consequential on endothermic or exothermic shown
*accept correct reasoning for **incorrect** answer from (b)(i)*

energy given out forming new bonds

*do **not** accept energy needed to form new bonds*

1

greater than energy put in to break old bonds

*accept exothermic **and** more energy given out than taken in for 1 mark*
*accept negative value for energy change **or** energy in products less than energy in reactants for 1 mark*

1

[10]

M15. (a) 1213.8 to 1214.3

*gains **3** marks without working*

correct answer not given then check working

1) moles of N_2 = $\frac{1000}{28}$ = 35.7 mol

***1** mark for each correct step*

*do **not** penalise rounding errors in this part*

2) moles of NH_3 = 2 × (answer from (1)) = 71.4 mol

3) mass of NH_3 = (answer from 2) × 17 = 71.4 × 17 = 1214 g

3

or

- 28g of N_2 → 34g of NH_3

  ***1** mark for each correct step*

- 1g of N_2 → $\frac{34}{28}$ = 1.214g NH_3

  *do **not** penalise rounding errors in this part*

- 1000 g of N_2 → 1000 × 1.214

  = 1214g

  allow error carried forward eg

or

- 1000 × $\frac{34}{28}$

  *gains **2** marks if correct answer not given*

  *1000 × $\frac{28}{34}$ gains **1** mark, **2** marks if correctly calculated*

  *(823.5g) 1000 × $\frac{28}{17}$ gains **1** mark if calculated correctly (1647.05g)*

or

other correct methods

look for the key ideas in the methods above

(b) 25 **/** 25.035 **or** ecf from (a)

*gains **2** marks even when there is no working*

*incorrect answer then 304/(their answer from (a)) × 100 gains **1** mark*

or using figures from part (b)

27.6 / 28

*gains **2** marks even when there is no working*

*accept 27 for **1** mark*

*if answers incorrect then304/1100 × 100 gains **1** mark*

2

(c) (i) increase yield

1

reaction is exothermic

or

allow decreased yield because rate of reaction is slower / fewer collisions for **2** marks

***must** get both points for **2** marks*

1

(ii) increase yield

1

plus **one** from:

- more (gaseous) reactant molecules than (gaseous) product molecules (owtte)

  accept greater volume on the left than the right owtte

- increased rate of reaction / more collisions

1

(d) any **one** from:

economic

- large town provides workforce
- workers do not have to travel far to the factory. (owtte)
- transport infrastructure already in place for large town. (owtte)
- factory brings prosperity to town (owtte)
- factory provides employment
- reduced tourism
- reduction in local house prices
- any other sensible economic factor linked to town

1

any **one** from:

safety

- escape of dangerous / harmful chemicals / gases (owtte)
  *do **not** allow polluting gases unqualified*
- danger of increased traffic
- risk of explosion.(owtte) /danger of high pressure
- consequences of an accident could be severe if the town is close
- any other sensible safety idea

1

any **one** from:

environmental

- factory might be unsightly (owtte)
- screening of factory (owtte)
- loss of habitats (owtte)
- plant trees/ hedges etc on and around plant site
- pollution of water / air / soil could harm plants / animals **or** noise pollution
  must be explained
- CO_2 is produced by burning fuels / heating
- CO_2 causes global warming / any effect of global warming
- eye sore
- any other sensible environmental factor

1

[12]

-

M16. (a) fewer product molecules than reactant molecules (owtte) **or**
accept forward reaction produces fewer molecules
accept left hand side for reactants and right hand side for products

3 reactant molecules and 1 product
or 3 volumes of gas becomes 1 volume of gas
accept high pressure favours the side with fewer molecules
ignore references to reaction rate

1

(b) any **three** from:

- low temperature gives best yield
  *accept add heat as increased temperature **or** 'less' as poor yield*

  or high temperature gives poor yield

- because the reaction is exothermic
  accept reverse argument if clearly expressed

- reaction too slow at low temperature
  or reaction faster at high temperature
  accept add heat and reaction goes faster

- temperature used gives a reasonable yield
  at a fast rate / compromise explained
  allow get less product but it takes less time
  *for **2** marks*

3

[4]

M17. (a) catalyst
accept speeds up reaction
or
lowers activation energy

1

(b) (i) an equilibrium is achieved when rate of the forward reaction is exactly the same as the rate of the backward reaction

1

(ii) in this equilibrium the forward reaction to form ammonia is exothermic

1

therefore if the temperature is low the yield from the exothermic reaction increases

1

(iii) in this gaseous equilibrium if the pressure is high this will favour the reaction that produces the least number of molecules, that is, the forward reaction to form ammonia

1

[5]

M18. (a) same number of (gaseous) molecules / moles / volume on both sides of the equation
allow particles for molecules
*do **not** accept atoms*
ignore amount

1

(b) (forward) reaction is exothermic

accept reverse answer

1

(c) any **three** from:

- particles gain energy
- particles move faster

  allow particles collide faster / quicker

  ignore move more / vibrate more
- particles collide more **or** more collisions
- more of the collisions are successful **or**
  more of the particles have the activation energy **or**
  particles collide with more force / energy

3

(d) any **two** from:

- more product (obtained in shorter time)

  accept better yield (of product)
- less fuel needed

  accept less energy / heat / electricity needed

  or

  lower fuel costs

  ignore cheaper unqualified
- less pollution caused by burning fuels

  or

  less specified type of pollution caused by producing heat / burning fuels

  *allow correct specified pollutants caused by burning fossil fuels eg CO_2 / greenhouse gases **or** correct effect of burning fossil fuels eg global warming*

  accept thermal / heat pollution
- using less fuel conserves resources

  accept sustainable

  accept fossil fuels are non-renewable

2

[7]

M19. (a) (i) nitrogen - air

accept atmosphere

1

hydrogen - north sea gas / natural gas / methane / CH_4

accept water / (crude) oil / coal / hydrocarbons / brine

1

(ii) *allow converse throughout*

- high temperature gives a low yield

1

- because reaction is exothermic

  must be linked to first bullet point

1

- but at low temperatures the rate is (too) slow

  if no other marks awarded accept 450°C is a compromise between yield and rate

  or

  *450°C gives a reasonable yield in a reasonable time for **1** mark*

1

(iii) nitric (acid)

accept HNO_3

1

(b) Ammonia / Haber process can be used to make fertiliser

1

with a specified economical reason
eg raw materials for Haber process readily available
eg transport costs are lower or no need to import
eg Haber process is a continuous process

ignore employment / labour costs

1

[8]

M20. (a) mixture is cooled / cooling

1

so ammonia / it condenses

or
so ammonia <u>turns into</u> a liquid (but nitrogen and hydrogen remain as gases)

1

(b) (i) exothermic reaction

accept reverse reaction is endothermic

or
equilibrium / reaction moves in the direction which raises the temperature

ignore answers based on rate or collisions

1

(ii) they / particles / molecules move faster **or** have more (kinetic) energy

allow atoms instead of particles

ignore particles move more / vibrate

*do **not** accept electrons (max1)*

1

any **one** from:

- particles / molecules collide more often / more frequently / more likely to collide

  ignore collide faster

  ignore more collisions

- more of the collisions are successful **or** particles collide with more energy / harder **or** more of the particles have the activation energy

  accept more successful collisions

1

(iii) more molecules / particles / moles / volumes on LHS (of equation than RHS)

accept 4 molecules / particles / moles / volumes on LHS and 2 molecules / particles / moles / volumes on RHS

or

greater volume on LHS (than RHS)

or

equilibrium / reaction moves in the direction which reduces the pressure / volume

accept converse

1

(iv) cost

or

difficulty in containing such a high pressure

allow risk of explosion

ignore dangerous

1

(c) (i) 60

1

(ii) 2.4(2857….)

*correct answer gains **3** marks with or without working*
accept any answer that rounds to 2.4
ignore units
*if answer is incorrect look for evidence of correct working to a maximum of **2** marks.*
moles of N_2 = 2/28 &#x003D (0.0714)
moles of ammonia = 2 × 0.0714 = (0.1428)
mass of ammonia = 0.1428 × 17 = (2.4276)
or
28 → 34
1g →34/28
2g →2.4… ….

3

(d) (i) 15

1

(ii) unreacted gases are recycled

allow unreacted gases are reused

1

rate (of production) is fast

accept production is continuous
ignore compromise between rate and yield

1

[14]

M21. (a) any **two** from:

- heat water / make steam / boil water **or** heat / steam used in stage 1 or from stage 3
- carbon dioxide from stage 3 used in stage 7 /to make urea
- nitrogen and / or hydrogen recycled
- ammonia and / or carbon dioxide recycled

allow unreacted material / gas recycled from stage 5 (to 4)
allow unreacted material / gas recycled from stage 8 (to 7)
*NB: if neither of the last two points are awarded unreacted material recycled = **1** mark*

2

(b) (i) increase yield

because (forward) reaction is exothermic

ignore references to rate

1

allow because (forward) reaction gives out heat

1

(ii) increase yield

ignore references to rate

1

<u>because</u> more (gaseous) reactant molecules than (gaseous) product molecules

accept <u>because</u> greater volume on the left than the right

1

(c) 76.9 - 77

correct answer gains 2 marks with or without working
allow 77 ***or*** *76.923…*
allow 76 ***or*** *0.77* ***or*** *0.76923 for* ***1*** *mark*
if answer incorrect allow ***1*** *mark for* ***either***

$$\frac{60}{\text{attempt at total } M_r \text{ of all reactants}} \times 100$$

or

$$\frac{\text{attempt at total } M_r \text{ of area}}{78} \times 100$$

2

[10]

M22. (a) air

1

(b) recycle

allow re-use

1

(unreacted) nitrogen and hydrogen

allow N_2 and H_2

1

(c) $N_2 + \mathbf{3}H_2 \rightarrow \mathbf{2}NH_3$

allow correct multiples

1

(d) *allow converse arguments*
ignore references to compromise

because a higher temperature would reduce (equilibrium) yield

allow higher temperature favours backward reaction

1

because a lower temperature would reduce rate

1

(e) (i) (energy of) reactants greater than (energy of) products

allow converse
allow (overall) energy decreases
allow energy required to break bonds is less than the energy released making bonds

1

(ii) line starting and finishing at same levels but with lower peak

1

[8]