

Part III May/June 2015

Paper 1, question 1

Average: 13.31 (stdev 2.63)

24 scripts

**Comments:**

vast majority of students were able to answer part (a) and part (b), although a few had some difficulties remembering to include 'units' on (b). part (c) of the question really separated the students who understood the entire course and could put things together.....such as determining several routes to prepare a diblock copolymer and evaluating the strengths and weaknesses of each.

Q 4

Part (a)-There were some very nice descriptions of various exchange mechanisms.

Part (b)-This was not well answered. No candidate could recall the pyrochlore structure although some guessed that spin frustration must be a good candidate for the observed suppression of magnetic ordering.

Part (c)-Answers to this part were mixed. Some candidates completely overlooked the role of Jahn-Teller distortion on determining the location of unpaired electron density, or misassigned its location. Not many candidates recognised the very significant exchange anisotropy in this lattice, which is necessary to understand the suppression of magnetic order.

**Q 6a (paper 1)** 32 answers. This was reasonably well answered although the quality of the 3D representations of transition states varied greatly. Almost all candidates identified the Evans aldol reaction in the first transformation, but several failed to assign the product stereochemistry correctly. In the second part, some candidates opened the iodonium ion with the wrong regioselectivity - and even those that got beyond the initial step got the stereochemistry of the epoxide wrong. Overall, this question was effective in testing the manipulation of chiral structures in 3D and converting these into "zig-zag" stereochemical representations.

Q6b

Most candidates were quick to find the  $6\pi$  disrotatory ring opening and closing. Few considered double bond geometries and the need for the intermediate ring to flip. Final part - should stay enantiomerically pure, unless there is an  $8\pi$  process too. Is the outcome a mixture of enantiomerically-pure diastereoisomers or a mixture of racemic diastereoisomers? "Racemic" does not mean "a mixture of diastereoisomers"

Q8

a) Book-work - many didn't compare and contrast between the 2 techniques, but instead concentrated on one of them. Disappointing response. b) This was covered in the lectures and also in one of the associated problems. Again, very disappointing response to a pretty straightforward question. c) This part was straightforward for practically all candidates. All students sketched correctly the potential-energy landscape for different models and achieved at least 3 marks for doing this. There were slightly incorrect answers in expressions for the transition rates.

mean =  $99/10 = 9.9$

Q9 18 scripts

- (a) distinction between HTS and FBDD generally well done
- (b) (i) Derivation of expression. Many did not derive expression but simply quoted it. Some confusion about signs or rigid body cost.
  - (ii) Some did not follow through to  $K_1$ , a few confused by sign of rigid body term. Some worked through in kJ and gave LE in these units.
  - (iii) Not well answered. Hydroxamic acid not seen as problem.

### Q10a Report

Part a of this question was done reasonably well. The mean mark (19 scripts) was 6.8, and the mean for the whole question was 13.3.

In part ai, the bi- and tridentate behaviour of TMEDA and PMDTA respectively in the solid state was generally well discussed though most candidates largely ignored discussion of solution behaviour beyond noting deaggregation. Just one or two candidates made more substantial points (e.g. abstracting the metal from the carbanion, bi/tridentate competition for PMDTA in solution). Only a very few candidates mentioned solid state evidence for the ability of TMEDA to bridge metal centres.

Part aii was done well. The structure of nBuLi was generally discussed well, though this was bookwork. Likewise, the effects of THF and TMEDA solvation were well handled. Most candidates proposed a reasonable polymer for the TMEDA-deficient system.

Q10 (b)

This was a simple recall from the lecture notes of the main types of synthetic routes to group 13 clusters.

The main points I was looking for were: reductive coupling starting from an M(III) organometallic halide or use of low-valent M(I) metastable compounds as starting materials.

There was relatively little discussion in the candidates' answers on actual synthesis and more on steric and electronic effects of ligands. Most highlighted the different situations of hexamers vs. tetramers depending on the metal's position in the group and the electronic nature of the organic ligand.

The strongest answers did focus on synthesis as well, particularly the method of using low-valent Al halides, as the disproportionation reactions produced clusters on the way to forming bulk Al metal which could be trapped by introducing appropriate ligands.

Some candidates discussed metal-metal multiple bonding which I could not credit as it was not within the scope of the question.

#### Q 12

23 Scripts in Total. Average mark 13/ 20.

Part a was reasonably well completed in most cases. In part B many students realised the Sharpless asymmetric dihydroxylation was best here, but the quality of the answers did vary with regard to correctly applying mnemonic, mechanistic details and the further transformations required.

#### Q14:

This question was answered slightly disappointingly, with marks ranging from 3 to 16, and an average mark of just 11.1 (over 15 scripts). Part (a) clearly asked for deductions about the electronic structure of the system described in the question, but several candidates focussed instead upon vibrational properties. Part (b) then asked for candidates to identify deuterated and semi-deuterated species on the basis of inelastic tunnelling spectra, which most succeeded in doing. Part (c) required candidates to state that changes in tunnel current can be due to changes in work function, changes in density of states, or both; most plumped for one or the other, but only a small number mentioned both possibilities. The hardest segment of the question was Part (d), where candidates had to speculate as to how one might achieve an STM image showing C-H bonds but not C-D bonds; this required extrapolation from the earlier parts of the question, and only a few came close to the correct answer. Overall, the performance was not too bad, but most candidates fell just a little short of engaging fully with the data provided.

#### Q15 (30 min)

This question was straight from the handout asking to define an equilibrium time correlation function (part a) and derive the fluctuation dissipation relation as given in part b. I expected part b to be the more difficult half of the question. The derivation, while given in the handout, is not exactly easy. However all answers were basically correct. Surprisingly it turned out to be part a causing problems which were of more conceptual nature.

For Q16, the average of 12.5 was close to target. A fair range of answers were given, only one of which got all details of the structure and its reactivity right (20/20, thus), but many understood some aspects but missed others. The question thus felt particularly well-targeted.

**Q18** This question was mostly bookwork testing the students' recall of material in the lecture notes. The mechanisms of squalene synthase and lanosterol synthase are quite tricky, however. Overall the question was done well, with most answers knowing the pathway at least in outline. Because the detailed pathway had been given in notes, these details were also expected in the answer, and this is

where many lost some marks. Only part (d) was new to them but most managed to see the relatively simple two-step mechanism (or something similar) to get to vitamin D3.

Paper 2, question 19

Average: 14.76 (stdev: 6.01)

22 scripts (\*\*\*) 3-4 students really bombed this question...so average is not really able to be brought up)

**Comments:**

generally the students did well on this question, however, some forgot that radical initiators such as BPO and AIBN were not really introduced to polymer chemistry in the early 1900s. also, many did not appreciate that 'at least 8 carbons' can also mean GREATER than 8 carbons and failed to recognise that an 8 carbon monomer for ADMET would not work.

Paper 2, question 20

Average: 16.86 (stdev: 4.37)

9 scripts

**Comments:**

the students who chose to answer this question had a good understanding of both synthesis and materials concepts presented in the course.

Q26

Answers to this question were generally pleasing. Almost all candidates were able to extract the required information from the graphs, and for part (a) were able to derive a sensible model for the magnetic behaviour. In part (b) the magnetic behaviour is more complex and fewer candidates were able to propose a model which rationalised all the observations.

**Q 29 (paper 2)** 26 answers. This question was generally well done although there were only a few excellent answers that provided a detailed account of mechanism and stereochemistry throughout. The more straightforward parts (a) and (b) were tackled well, although a handful of candidates mixed up the step order and proposed an unlikely directed epoxidation involving the TBS ether. In the more testing part (c), most candidates generated the required boron dienolate but many failed to account for the enforced  $\alpha$ -regioselectivity in the aldol addition with the aldehyde component based on the cyclic mechanism. As expected part (d) was the most challenging and there was a large spread of answers, some of these with highly improbable mechanisms (such as using the  $\text{SmI}_2$  as a Lewis acid). The best ones recognised that the reductive cyclisation must involve a radical pathway (SET) but few of these tried to invoke chelation by the Sm to explain the stereoselectivity. In the final part of the question, most came up with reasonable suggestions for an enantioselective synthesis.

### Q30

- (a) Reasonable attempts; initial attack on N=N bond leads to confusion; alternative attack on C=C produces tBuO<sup>-</sup> as base
- (b) N-heterocyclic carbene - missed by many even though there was a question on NHCs last year. Candidates were expected to know that DBU is a base.
- (c) Not many people noticed that the formation of the iminium would also deprotonate phenol, to attack boron. This turned out to be the hardest part of Q30
- (d) Was answered very well by most candidates, even though it is an unusual process

### Q33 17 scripts

The question was in 6 parts which made it easier for the candidates to get an average mark. There was little in the answers testing material in the course that went beyond what was in the handout. The parts looking for additional insight were poorly done.

- (a) Somewhat disappointing descriptions of the anomeric effect. Few picked up the stereochemical issue for the given acetal.
- (b) Some did not think to open the ring to exchange the anomers, although they had been told about this.
- (c) Generally well done, based on what they new for equatorial-equatorial glycosidases
- (d) First part too repetitive of part (c). Very few really good answers to trapping and characterisation aspect.
- (e) Formation of E – a wider range of answers, most were correct. The significance part not answered particularly well.
- (f) Not as well done as expected. Some parts clearly remembered. Very few recognised Tamiflu as a prodrug.

Q34 enclosed.

No of scripts: 8

Marks: 10, 13, 14, 15, 16.5, 17, 17.5, 20

mean = 15.375

Part III Paper 2 Q34.

Part (a) was answered correctly by the majority of students except one case when the vacancy mechanism has been suggested for ionic conduction in AgI.

Part (b) was challenging and only one student has achieved maximum mark for this part. The main difficulty in the derivation of expression for mean squared displacement through the velocity-velocity auto-correlation function was in finding correct limit for integration.

Part (c) was of intermediate difficulty. The main challenge was in realising that parameter b is related to the time of diffusional jumps.

### Q37 Report

This question was attempted by 15 candidates and was generally quite well done. The mean mark was 16.5.

Part a was bookwork and most candidates saw how stacking in the HMPA complex was not allowed on steric grounds, though a few answers suggested a pseudo-cubane. The laddering in compound **B** was generally recognised, though only about 50% of respondents remembered that cyclization occurred.

Part b required that candidates knew BuLi and TMPH react to form a lithium amide – knowing that this was a tetramer (unusual for lithium amides) was bookwork and caught out quite a few. Formation of the aluminate was generally tackled well though a few candidates ignored the THF and suggested polymer formation. Generally discussion of the structure core (AlNCLi ring) was well handled.

Part c caused quite a few problems; a bit of a surprise because it was a disguised reworking of a previous tripos question. Several candidates missed the identity of **E**, suggesting ortholithiation instead of benzylic lithiation. The nucleophilic attack on the nitrile was badly handled by a surprising number of candidates, so not correctly identifying **F** was a common issue. Most candidates suggested a reasonable rearrangement of **F**. Even if they started from the wrong compound and therefore missed the correct identity of **G**, they still got some marks for a plausible rearrangement. The crystal structure of **G**<sub>2</sub>.DME polymer was generally very well dealt with even if **G** had not been identified correctly since even in incorrect suggestions for **G** the basic components were all there; the pyridyl N, the Li<sub>2</sub>N<sub>2</sub> core, the bridging DME. This enabled a plausible structure to be proposed in the vast majority of scripts.

#### Q. 38

- (a) The first section called for simple recall of the principles of metal-metal multiple bonding in the p-block and how these changed on descending the group into the heavier main group metals. The main principles were the increasing manifestation of the inert pair effect – the reduced tendency of s electrons to become involved in bonding resulting in bent rather than linear geometries and a reduction in the actual bond order. This introductory section was generally answered very well; all students were able to recall and describe the effects of the above phenomena. Differentiation was made on the basis of detail provided in the descriptions and diagrams of the various bonding situations which occurred. Credit was also given to the mentioning of relativistic effects at the bottom of the group.
- (b) Part b was an extension of the topics discussed in part a which probed the students' understanding of the bonding described by introducing the effect of additional donor electron pairs. An example of this reactivity had been given in the lecture notes. A very wide spread of answers was given. Most students recognised a decrease in bond order as vacant orbitals were filled with ligand donor electrons rather than metal-metal donor acceptor bonding interactions. The strongest few candidates correctly identified the lack of change in bond order with the first addition implying the initial compound had a bond order closer to two rather than three.
- (c) The final part was designed to be challenging by drawing on material from part II chemistry and applying it in an unfamiliar situation. Most candidates were able to answer part i as this

had been discussed in lectures and was similar to a previous tripos past paper, although none had correctly accounted for the valence electrons to calculate the bond order between Mo and Ge. Part ii should have been straightforward to any who could recall the topics in the part II chemistry A1 course on metal-ligand multiple bonding. Unfortunately, only one candidate was able to correctly identify the pi molecular orbitals and number of bonding electrons, although had forgotten to account for filled non-bonding  $d_{xy}$  orbitals on Re. The final marks scheme was therefore adjusted to take into account the difficulty in answering c part ii.

#### Q 39

Almost all students correctly identified the aromatic nature of the molecule in part (a)(i), but a number did not fully explain their answer in terms of all the criteria for aromaticity (planarity, cyclic,  $4n + 2$  etc.). In part (a)(ii) there were many good suggestions, but several students wasted time by just describing what clinical trials were rather than answering the question. In part (b)(i) attack of ammonia at the furan 5-position and then subsequent ring opening was got by about half the students. Very few converted the ester to an amide first, a highly likely first step under the reaction conditions. A surprisingly large number proposed a highly strained bicyclic intermediate (Bredt's rule forbidden) for this process by cyclising onto the 5-position with the group in the 2-position. Most students could draw mechanisms for part (b)(ii) but many wrote no words to explain the regioselectivity of the reaction with chloroacetone or with the Mannich reagent. Only a few students considered the delocalisation of the lone pair on the 2-amino substituent into the pyridine ring as the reason for the observed selectivity. A good proportion of students spotted the inverse electron-demand Diels-Alder reaction in (c)(ii) and gave good explanations for the regioselectivity in terms of orbital coefficients and the conversion of a less aromatic to a more aromatic molecule/loss of nitrogen as the driving force. A number of students did not spot the enamine formation and instead proposed a titanium enolate for the dienophile. Part (c)(ii) was the most challenging part of the question, however some big hints could be obtained by noting the similarity with the conversion of B to SCH 28080. The 2-amino pyridine was the key intermediate. This could be installed in one step *via* a Chichibabin reaction. This was covered in the lecture course but got by very few students. The amino group was key to directing a successful bromination, both in terms of regioselectivity on the pyridine ring and also making the pyridine ring more reactive than the benzene ring for an electrophilic bromination. A number of students suggested reagents of the wrong oxidation level for the final condensation suggesting that this concept was not well understood.

24 scripts were submitted. The average mark for this question was 15.75, with a standard deviation of 4.73. This is a slightly lower average than would normally be expected, but this was due to 4/24 scripts being of a very low standard (<40%).

Dr Ben Pilgrim, June 2015

#### Q40

This was the easier of the two medicinal chemistry questions and by far the best answered, with almost all students making at least a reasonable attempt at most parts. In part (a) most students rationalised the greater acidity of the S-H bond over the C-H bond and the 'soft-soft' interaction between the thiolate sulphur and the alkyne carbon to get the correct starting point for this question. Many could identify it is a 5-enolexo-exodig cyclization from Baldwin's rules, although very few explained the orbital overlap reasons that lie behind this. In part (b) almost all students suggested a good forward synthesis with the correct reactions in the right order. However, the conditions were often not well specified. The first step is a Friedel-Crafts acylation which requires a Lewis acid such as  $\text{AlCl}_3$ . The nucleophilic aromatic substitution requires a strong base to form the alkoxide such as  $\text{NaH}$ , but many students suggested a base that would be too weak, or that would compete as a nucleophile such as methoxide. A large number of students wanted to use  $\text{HCl}$  to cleave the methyl groups off of the phenol ethers – these groups do not fall off in  $\text{HCl}$ ! The deprotection would likely be *via* an  $\text{S}_{\text{N}}2$  pathway and so  $\text{HBr}$  or  $\text{HI}$  for a start would be much better due to the more nucleophilic anion, alternatively  $\text{KOH}$  or a thiolate would be good. The most commonly used reagent is of course  $\text{BBr}_3$  here. Many students suggested good reasons for introducing the new biaryl bond in part (c)(i), but many did not talk specifically about preorganization for binding, i.e. the restriction of rotational freedom and hence the less unfavourable entropy term contributing to overall better binding. In part (ii), initial addition to the aldehyde was spotted, but students suggested a huge range of mechanisms for thiophene formation including many unlikely looking nucleophilic attacks on an electron-rich aromatic ring. The correct answer – loss of water to give a cation and then this being trapped by the electron-rich ring (or an electrocyclic process) was suggested by only the very best. The conversion of the enamine to the thioester was well done. About half of the cohort got the aldol reaction and the subsequent opening of the thioester and ring closure by conjugate addition. Significant numbers got the need for chelation (by  $\text{LDA}$  or similar) as being necessary in part (iii), but many forgot the need to do a deprotection afterwards.

24 scripts were submitted. The average mark for this question was 16.77, with a standard deviation of 3.51.

Dr Ben Pilgrim, June 2015

#### Paper 3 Question 41 – L1 Catalysis in Synthesis

21 Scripts in Total. Average mark 17.0 / 25.

Part a seemed to be more challenging than anticipated. While some students did very well, a significant failed to see the parallels with Wacker-type chemistry.

Part b in general was tackled very well by most students. The best answers used the quadrant diagram of BINAP from the asymmetric part of the course and rationalised the enantioselectivity of the reaction and specified *S*-BINAP as the correct enantiomer. There were an encouraging number who got this. Also the best answers picked up on the linked Heck- $\pi$  allyl chemistry and included proper discussions of the stereochemistry involved.

Part c saw a range of strategies. A double Heck approach was common, although the finer aspects of double bond isomers which would result were mostly not discussed in these answers. The ideal approach of a tandem Heck-Suzuki was deduced by several students. There were a couple of other creative strategies which got appropriate credit, as well as a relatively small number of scripts where the student got quite lost.

#### Paper 3 Question 42 - L1 Catalysis in Synthesis

16 Scripts in total. Average Mark 16.25/25

Part a – There were several approaches to this that came back. The ideal one of a copper catalysed aldol addition was recognised by a number of students. A number of others used an enamine approach, which would likely not work with the fragments commonly suggested, but appropriate credit was given for rationalising the stereochemistry through.

Part b – The first part was quite challenging - the best students saw how to correctly use the iodosobenzene as a nucleophile, to achieve epoxidation in the first part. In the second part, the majority saw the initial reduction and subsequent Michael addition cascade process. A good number were able to properly rationalise the stereoselectivity and this was largely well answered.

Part c- Generally well done – most students saw the cis reduction/Jacobsen epoxidation as the best way to do this. Appropriate credit was given for other approaches where due.

Overall, the average would be significantly higher if one script was excluded, where the student barely attempted any of the questions and only 2/25 could be awarded. If this were excluded, the average would be 17.2/25.

#### Paper 3 Q43

Generally good.

The general description of DLVO was good including the effect of pH, salt and valency. The point of zero charge was correctly stated by approximately 1/3<sup>rd</sup> of the candidates. The second and third parts were also generally well answered although a few candidates could not recall the equation for ionic strength. The description of aggregation and flocculation was generally good as well as the scattering methods to characterise the flocs. The adsorbed polymer section, did present a few challenges although most candidates made a reasonable attempt. Very few could outline the mushroom and brush regimes. Most candidates could describe depletion flocculation.

This question was attempted by 25 candidates.

#### Q45:

This question was answered pretty well, with marks ranging from 5 to 24, and an average mark of 16.9 (over 11 scripts). Part (a) required some deductions to be made about the energy-wavevector relationship for a Shockley surface state, based upon photoemission information. Over half the candidates got this entirely or nearly correct; some others made slips and/or failed to spot that an abrupt vanishing of the photoemission signal would be

much more consistent with a band crossing the Fermi level than with one entering resonance with bulk states (the latter situation would anyway lead to an insoluble problem, which candidates ought to have realised). Part (b) required candidates to estimate the change in work function due to adsorption of ammonia, given certain assumptions; again, more than half answered this entirely or nearly correctly. Part (c) solicited suggestions for how the assumptions in the previous part might be incorrect, and asked what the effect of this might be; nearly all the candidates did very well here, although this was only a relatively small component of the question as a whole. Part (d) considered the possibility of ammonia dissociation to give adsorbed nitrogen adatoms; those who read the question properly generally got this correct, with wrong answers mainly coming from candidates who assumed the formation of nitrogen molecules. The overall performance on this question was, nevertheless, more-or-less in line with expectations.

#### Q46:

This question was tackled really quite well by all the candidates who attempted it, with marks ranging from 13 to 23, and an average of 17.9 (over 15 scripts). Parts (a) and (b) required calculation of work function and absolute resolution, based on information given for a concentric hemispherical analyser used in the detection of photoemitted electrons; almost all candidates did very well here, with very few dropped marks. Part (c) asked for a comparison between two different modes of usage for the analyser, and here there was a more mixed performance. Similarly, performance in Part (d), which asked about signal-to-noise versus resolution, was also mixed, as was that achieved in Part (e), which asked about Auger spectroscopy. Overall, however, candidates exhibited a good understanding of the principles involved, albeit this was demonstrated more clearly in their ability to manipulate formulae than in the clarity of their discussion.

#### Q47

The five attempts at Q47 were of a generally high standard, average mark 74.8%. Candidates had difficulty remembering the differences between bound and scattering wavefunctions in (a)(i), but almost all could accurately sketch and describe the reaction probability in part (a)(iv). Few realised that increasing the width of a barrier made it appear more classical in (a)(v). Most were able to derive one-dimensional transition-state theory from the flux-side time-correlation function in (b)(i) but proving one-dimensional TST is exact caused difficulties (or was left unanswered) in part (b)(ii).

#### Q48 (45 min)

This question was answered by the majority of the students taking this course, presumably because it seemed rather familiar. Indeed, it involved applying the harmonic approximation to a two-degree of freedom potential (part a and bi) with the complication in part bii that the harmonic approximation breaks down at the transition state for the coordinate perpendicular to the reaction coordinate. I was pleased to see that most of the students saw this and set up and even computed the correct integral. More disappointing were the answers to part aii and bi. In particular the computation of the partition function of the reactant in the harmonic approximation (bi) turned out to be challenging with wrong answers or no answer at all. Evidently the concept of a normal mode is still not as obvious as it should be.

For Q49, the average of 15.6 was brought down by two of the 11 students getting only 5/25, which were essentially aborted starts. Many of the others did quite well, showing a sophisticated grasp of

the fundamentals underlying the question. Candidate 8137T had an additional page brought separately as it had been included with Q43; I believe this page constituted preliminary brainstorming notes, as the candidate also submitted a complete answer, gaining 22/25 marks. The page has been appended to the end of his/her script.

For Q50 Although the average mark of 13.6 was a bit low, it reflects me going back through and remarking upwards. Many students did quite well, with 5 gaining 19 or more, but the average was brought down by some students' struggling with basic concepts. Few got the key catenated structure right, but many of the highest scorers were able to do well by proceeding with sound thinking and reasoning based upon the wrong structure.

**Q53** This was answered by a relatively small number of students, who did not do too well, with one notable exception. It seems that most students answering one question on this course went for Q54, which presented a more easily recognisable approach to the main parts of the question. It may have been the more desperate students who started this question in the hope that they would be able to work something out. In fact the correct answer here is considerably shorter than the answer to Q54. There was a question similar to part (b) in the handout (but with O instead of N in the ring) but very few recognised this.

**Q54** This was answered by a relatively large number of students, who did pretty well on parts (a) (i) and (ii) and (b) (i), which were essentially bookwork, and were therefore marked fairly strictly. Many floundered on (a) (iii) which needed a pinacol-type rearrangement (a similar reaction was in notes as part of gibberellin biosynthesis). In part (b) (ii) most did the phenol oxidative coupling and the dienone-phenol rearrangement but this ended them up with a phenol group that they couldn't deoxygenate. This problem is solved by reducing the ketone before the rearrangement (similar to a step in morphine biosynthesis).

## **Marker's report on IDP1 Atmospheric Chemistry and Global Change 2015**

### **Question 1**

15 candidates attempted this question. The average mark for the question was 16.3 out of 25 (65%), with a standard deviation of 4.8. The marks ranged from 7 to 23.5 out of 25. The tables below show the number of candidates whose marks fell in different bins and the average mark attained for each part of the question.

The question concerned metrics for the climate impacts of trace gases and included a number of mathematical components. Since the calculations in different parts of the questions were linked, candidates were not penalized multiple times for an error

(i.e. if the calculation of the mass of the atmosphere in (b)i was incorrect, the calculations in subsequent parts that relied on (b)i were not marked down again unless a different aspect of the calculation was wrong).

Part (a) was a written component about Ozone Depletion Potentials. There were a number of aspects that could be discussed, and any relevant point was allocated a mark. Most candidates performed well in this part. Part (b) was concerned with calculating mixing ratios and radiative forcings for mass emissions of trace gases. Common errors included: not converting the value of emissions given from Gt(C) to Gt(CO<sub>2</sub>); not converting mass mixing ratio to volume mixing ratio for the radiative forcing calculations. Nevertheless most candidates made a reasonable attempt at these calculations and scored reasonably well.

Part (c) was concerned with calculating the Global Warming Potential for CFC-11. This

was the part of the question that most candidates struggled with and the average marks for this part were considerably lower than for parts (a) and (b). It is worth noting again that calculation errors introduced in part (b) were not penalized for in part (c). Therefore a candidate who managed to manipulate the expression and calculate a GWP could still gain marks even if their result was not quantitatively correct. Despite this many candidates struggled to derive the correct expression and calculate a GWP. Candidates who did not perform well in part (c) also tended to have not performed well in part (b), and vice versa. This contributed to the bimodal structure of the overall marks for the question.

The marks used were (out of 25): (a) 6; (bi) 2; (bii) 3; (biii) 2; (biv) 3; (ci) 2.5; (cii) 1; (ciii) 3; (civ) 2.5. These were slightly amended from those given in the exam to account for the fact that many students did not perform well on parts (c)iii and c(iv).

#### IDPQ2

In general, the candidates demonstrated a good understanding of the main ideas explored in this question. The standard was high.

Many candidates were able to calculate the temperature of the atmosphere (although none spotted a straightforward short cut). Those candidates who got the wrong answer usual made a simple sign error in relating the incoming flux and the outgoing IR from the atmosphere and surface.

Some candidates struggled with finding the temperature dependence of ozone. Some clearly found the differentiation beyond them, while others disappointingly did not manipulate the Chapman equations into the required form.

36 answers with a mean mark of 16.63

#### IDPQ3

A rather straightforward question that some candidates managed to make much more complex.

The roles of methane were generally discussed well. Candidates were then asked to perform a simple calculation to calculate the mixing ratio of methane. A surprising number attempted instead to calculate the methane number concentration, despite not being given all the relevant information (which they mostly remembered). Their attempts displayed a worrying inability to manipulate simple units.

The ice core part of the question was answered well – credit to our ‘drop-in’ lecturer. Most candidates could use the Clausius-Clapeyron successfully.

22 answers with a mean mark of 17.0