Paper 1 – questions are marked out of 20

Q.1. (Advanced polymer chemistry) 23 scripts. Average 16.15/20, Range 10.5 to 19.
(a) i) most of the students answered okay, however a few missed MeOH condensate
(a) iv) almost all got alternating copolymer correct
(b) several students did not read the question correctly and they did not produce the plot requested; also many did not understand the living nature of metal-mediated single-site catalysts.
(c) all the students got this correct.
(d) The students in general had a reasonable idea of what controlled hydrodynamic radius but very few provided sensible options for techniques to use a detector for a GPC.
Overall a good average was achieved which demonstrates the students overall performed at a good level in this course.

Q.2. (Inorganic materials) 24 scripts. Average 11.8/20, Range 3 to 18.
Both parts of the question were mostly done to an acceptable standard. In part (a) some candidates got the number of d electons wrong, which led to incorrect assignment of the magnetic orbital. Most candidates covered the main features in (a)(ii) but discussion of the decrease in chi due to short range order was superficial in many cases.
Some candidates incorrectly assigned oxidation state is part (b) due to a variety of reasons. All answers to part (ii) chose to ascribe the small moment due to some type of antiferromagnetic coupling, rather than band formation and Pauli paramagnetism. This approach can work, but requires identification of the T ground term for Re^{6+} as the source of the required anisotropy.

Q.3. (Bio-inorganic chemistry) 20 scripts. Average 13.3/20, Range 6 to 19.5.
Several scripts got full marks for each part of the question but no one script got everything right. So each part was interpretable and do-able.
(a) 6 marks in total; 3 were awarded for getting the pKa of the Cys residues in the trimer, which is a gimme, especially as we had done exactly these type of questions in supervisions. Few students recognized the symmetry of the system. Several students got mixed up thinking the trimer was the 'standard state' and the monomer would be the 'altered state'.
(b) Full mechanisms were not expected, rather just how each reaction was associated with each enzyme and how many electrons were needed for each cycle. Many scripts included attempts at mechanisms, which were not all entirely correct, but I did not really penalize them for that unless they got the electron count wrong. The best answers simply pointed out reactions 2 and 3 are 4e oxidations of the substrate while in reaction 1 only 2e come from the substrate hence why another 2e are needed from a reductase.
(c) Here some students misinterpreted the question. In part (i) "WT CYP119 protein" meant the unmutated protein (with heme replaced by a methyl iridium porphyrin as stated in the preamble) but several scripts interpreted the question to mean the WT protein containing heme is inactive for this reaction. That is also true, but not what was meant. Those who gave this answer were not penalized as long as they picked up with the Ir-Me porphyrin in subsequent parts of the question – not all did. Note this final part (c) related to a specific

paper we discussed in supervisions. There should have been no reason to misinterpret anything.

Q.4. (Soft matter – from molecules to materials) 32 scripts. Average 13.0/20, Range 8 to 18.5.
The question was well answered in general. Questions corresponding to parts of the course that were not examined in past papers were generally answered less well (e.g. parts a and b). This highlights the need for candidates to cover the whole material when they revise for the exam and not only rely on themes appearing in past papers. Another common error included candidates forgetting to use the correct sign for the van der Waals force.

Q.5. (Energy landscapes and soft matter) 12 scripts. Average 13.9/20, Range 10 to 17.5.
(a) was mostly done well although some candidates did not explain the basic assumptions of the AO model (e.g. that polymers are modeled as spheres that can interpenetrate).
(b) was done rather poorly, many candidates did not identify the configuration of minimal free energy (perhaps through a failure to read the question carefully).
(c) many students made sensible comments but a good explanation would include a brief description of what dispersion forces are, and how they differ from depletion forces.
(d) Most candidates scored more marks on the energy landscapes part of the question. Several produced correct answers for all parts of the first passage time and dynamical activity calculations. Since the marks were generally lower for the soft matter part the overall result for this question looks satisfactory. There were no poor scores.

Q.6. (Stereocontrolled organic synthesis) 42 scripts. Average 13.1/20, Range 5 to 18.5.
(a) Students did well on this first part of the question, averaging 7-8 marks. Most picked up marks for correctly identifying and drawing out the reaction mechanism and for correctly assigning the intermediate E silyl enol ether. Students primarily lost marks for poorly drawn 3D intermediates and transition states which then often led to incorrectly identifying the stereochemistry of the product.
(b) The key thing to highlight is that both sterics and basicity play a role. Diisopropylethylamine and triethylamine have similar basicities but one is much more sterically demanding than the other. Both require coordination of the Lewis acid before deprotonation and the more bulky base has a greater preference for the less hindered side. Most answers commented on this steric effect. DBU is a much stronger base which can probably deprotonate without the aid of the Lewis acid and with an earlier transition state as the reaction is more exothermic than for the other bases. This reduces, but does not invert the preference for A.
(c) Most candidates spotted that this is a pericyclic process, but many did not label it as an 8πa conrotatory electrocyclic process nor explain the geometric and stereochemical consequences

Q.7. (Computer simulation methods) 11 scripts. 12.3 /20, Range 8.75-16.75.
Overall, the question was well answered. Students scored lowest in part (b) of the question, with an average of 4.1 out of 8 marks. Parts (c) to (f) were answered satisfactorily. The most diverse responses were for part (a) – where it appears that many students can't distinguish pseudo code (as required) from actual code.

Q.8. (Main group organometallics) 27 scripts. Average 11.9/20, Range 4 to18.

(a) The first part of this question was not done as well as I would have hoped. Many answers used the wrong amount of TMEDA and many candidates failed to perceive the importance of conjugation in this system. Specifically:

NMR data had to be marked slightly more leniently than expected; the doublet in **A** should have been attributed to coupling with phosphorus and the role of electronegativity in ordering the 1H peaks in **B** would have been expected.

Though chelation was largely correctly identified for **B**, many candidates suggested a dimer and not a tetramer. To some extent this was because they were thinking about lithium amides – though in this case the structure core is based on LiO and not LiN bonding. LiO allows stacking.

In quite a few answers, **B** was not made to be conjugated and the candidates drew the initial lithium imide instead. Even if they did rearrange the imide, quite a few candidates suggested the rearrangement was due to the relative hardness of O and N rather than conjugation.

Many candidates used 1 eq. TMEDA wrt Li when drawing a structure for **C**. The result was often a very symmetrical structure that would not yield the quoted Li NMR data.

(b) (i)   This was generally answered well with most candidates able to recall both bonding models, recognise the atom hybridisations in both and that the true bonding picture is a combination of both models.

(ii) This part of the question was answered less well than expected. Several candidates observed that the reaction between an Al-hydride and alkyne would result in *syn*-addition and subsequent rotation about the double bond was needed. Although specific reference was made to the bonding in Al-aryl dimers in the question, most candidates did not discuss the bonding in these systems which was covered in lectures. Marks were awarded to any who did. Very few recognised the similarity with the alkenyl complex in the question and the alternative bonding mode having a C-C single bond enabling rotation and switching of stereochemistry to the more stable form. A large proportion of candidates thought an Al-alkynyl complex was formed.

(iii) The final part was generally answered well. A large proportion of candidates noticed how a non-interacting lone pair on the P and vacant orbital on the Al could result in a cycloaddition reaction across the C=O in CO_2 with the O bonding to Al and P bonding to C, forming a heterocycle. Marks were awarded for correct product and mechanism. Some candidates incorrectly attributed the conversion to reaction across the C=C double bond.

Q.9. (Aromatic heterocycles and medicinal chemistry) 51 scripts. Average 12.9/20, Range 8 to 19.

This was a popular question, with 51 attempts (over half the cohort).

(a) The typical reactivity of 1,2,4-triazoles was not well known. Many candidates thought that DBU would not be strong enough to deprotonate the triazole (several suggested pKa values of around 16-17, presumably by analogy with pyrrole) and so had the neutral triazole doing the alkylation. Among those who did deprotonate it first, not everyone realised that the anion was delocalised and could react on any of the nitrogens. Some seemed to think that the negative charge could only be on one nitrogen at a time and suggested that it

would prefer to be in N4 in order to avoid repulsion with the lone pair of an adjacent nitrogen if it was on N1. Others suggested that the charge would prefer to be on N1 so that it could be stabilised by inductive withdrawal by N2, leading to alkylation on N1 being preferred, while still others reached the opposite conclusion (alkylation on N4 preferred) on the grounds that the inductive withdrawal would reduce the charge density on N1. The observed outcome (alkylation on N1) was perhaps most simply explained using the alpha effect (interaction of lone pairs on adjacent nitrogens), but even then it was common to discuss the lone pair repulsion in the context of the stability of the product with the implicit (and in some cases explicit) unlikely assumption that the alkylation would be under thermodynamic control.

In total the majority of candidates (33) did predict alkylation on N1, with the remainder either alkylating N4 (9) or alkylating on carbon (9). The typical regioselectivity of triazole metalation was even less well known: of those who correctly alkylated N1 in the first step only 7 candidates correctly predicted ortho metalation at C5 compared to 22 who predicted metallation at C3 instead. One candidate, at least, remembered that this had been mentioned in the lectures, writing (after initially metalating C3) *"Actually no, I vaguely remember in notes that it reacts @ C5"*. Reactions involving metalation on carbon, nucleophilic addition of TMP to the ring, and even an attempted cycloaddition were also seen.

(b) A range of suggested mechanisms were seen for this part. The expected answer was a (possibly stepwise) cycloaddition of the quinoline oxide onto the alkyne, followed by rearomatisation, but it was more common to see the phenol cyclising onto the alkyne first to give an enolate (despite the acidic conditions) which then attacked the quinoline oxide. This mechanism involves either drawing an allene in a 6-membered ring or localising a negative charge on an sp^2 carbon; either way several candidates who initially drew this mechanism made comments such as "*Looks very unhappy*" or, in one case "*cyclic allene is bad, silly, does not happen*". Almost any suggested mechanism received some credit, with the number of marks awarded reflecting how plausible it was. The reactivity of isoquinolines (electrophilic at C1) was well known and most candidates were able to pick up some marks for this part.

(c) Most candidates realised that they had to hydroxylate the benzene ring, and answers could be divided into those where this was drawn as a simple radical rebound mechanism (sp^2 radical) and those where the candidate remembered that it involved the pi system and the NIH shift (misnamed as 'NHS' by one candidate). Loss of the piperidine unit proved surprisingly problematic, with many candidates feeling the need to hydroxylate the nitrogen or the carbon next to it using the P450.

Q.10. (Catalysis in synthesis) 40 scripts. Average 13.1/20, Range 5 to 18.
Part (a) was seen by many students to commence with oxidative addition of Pd(0) into the C-I bond, followed by insertion into the alkyne. Following this a range of answers was obtained with some students correctly identifying the full sequence of 1,2-migratory insertions followed by a terminating beta hydride elimination. Part (b) – quite a few students spotted that for so many stereocentres to be formed in one go in a ring from achiral starting materials a pericyclic reaction was likely, specifically a cycloaddition and a

number got the exact partners correct and proposed plausible catalysts to achieve this. The most likely would be a metal bisoxazoline complex as the alkene has a pyridine N-oxide attached that can provide bidentate binding, as seen extensively in the lectures. Other reasonable approaches were given appropriate credit.

Q.11. (Electronic structure of solid surfaces) 24 scripts. Average 12.7/20, Range 3.5 to 19. Part (a) was generally well done - essentially a repeat of a derivation in lecture notes. Part (b) was more tricky, where some got the correct numerical answer, others did not. Given this part was 4 marks, some credit was given where sensible issues were raised/values calculated, or where there was a minor slip/factor. One candidate calculated the total dipole and only converted in a later part of the question and was given a small credit. Part (c)was well done with most candidates giving several sensible comments, no-one made a significant attempt at a quantitative analysis. Most candidates gave some sensible comments in Part (d) referring to intermolecular interactions that will have some effect on the mechanisms mentioned in part (c). Part (e) got a mixture of answers, although a good number made sensible comments about reaction/disintegration of the ammonia. Some raised the issue of surface reconstruction. Rather few specifically mentioned the desorption to give an essentially bare surface.

Q.12. (Chemical biology and drug discovery) 37 scripts. Average 12.4/20, Range 7 to 18.5. This question was generally moderately-to-well answered.
Few students realised in part (a)(i) that the reason why a slow kinetics reactions can be used to label glycans on the cell surface, is because of the high density of their presentation which is different for single-protein labelling. In part (ii) many students could not clearly show how the neighbouring groups can accelerate the hydrolysis of the iminophosphoranes, while part (iii) was overall well answered. In fact, and perhaps the most difficult part, (b) was very well answered by some students which highlighted the 1,3-dipolar cycloaddition followed by the [4+2] retro to release CO_2 which drives the formation of the product.

Q.13. (Solid electrolytes) 20 scripts. Average 12.1/20, Range 2 to 17.
(a) This part of the question asked for defect reactions describing the incorporation of metallic sodium in NaCl and the aliovalent doping of NaCl by YCl_3. Most candidates correctly identified two variants of each of these processes, and correctly argued in favour of one in each case in terms of relative ionic-radii values. Many correctly associated the creation of Cl and Na vacancies, respectively, with increased ionic diffusion/conductivity of the relevant ions. However, none mentioned the 'colour-centre' opto-electronic behaviour of electrons trapped in Cl vacancies in the case of excess Na incorporation.
(b) All the candidates gave correct definition of the diffusion coefficient but some forgot to describe the origin of factor two in the denominator. In the estimate of the diffusion coefficient in high-temperature phase of silver iodide not all the applicants used the correct value for the energy barrier, i.e. 0.05 eV.
(c) The majority of the applicants very successfully answered this part of the question. Just a few applicants did not give the expression for diffusion equation in one dimension which should be the basis for dimensional analysis.

Q.14. (Supramolecular chemistry) 27 scripts. Average 12.4/20, Range 5 to 19.
Most had some sense that **3** reacted more readily than **4**, and through a radical mechanism. Most also saw that the ammonium group of **4** bound to catalyst **2**, although few were able to predict a ketone product - generous partial marks were thus given. Some thought perchlorate might act as an oxidant or base, incorrectly, although most deciphered that barium would bind to the crown ethers competitively, displacing the ammonium group and switching selectivity back to what was observed in part (a). Relatively few predicted that **4** would react to form a multitude of products, with oxidation occurring along its chain.

Q.15. (Chemical dynamics and machine learning) 6 scripts. Average 11.7/20, Range 3 to 15
Six answers for this question. Five of the six answers for this question were decent efforts, while one was presumably out of time and had no proper answers. Some of them did not derive the results in (c) but just stated it. In the last part the better answers went into more detail for the accuracy measure and mentioned the area under curve metric.

Q.16. (Total synthesis) 26 scripts. Average 12.9/20, Range 2 to 20.
Overall, this question was fairly average. The first part was pretty straightforward in terms of a Diels Alder reaction, but many people answered this poorly. The second part was also fairly straightforward but many students missing elements directly included in lectures. An average mark was fairly was easy to hit. Not many very well answered scripts and not many very poorly answered.

Q.17. (Biosynthesis) 12 scripts. Average 13.1/20, Range 5.5 to 17
Part (a) (i). Explaining why each carbon showed three peaks was mostly well done but the explanation of how the ^{13}C data was analysed was not well done. The question did not explain that the carbon that showed a singlet was nevertheless ^{13}C enriched. Some students assumed in (a) (ii) that it was unlabelled and introduced in a methylation reaction. This was not the most plausible answer but was conceivable, so this only lost them one or two marks. In (a) (ii) most students just gave one variant of the pathway, despite that fact that there were two to explain, and so lost half the marks. In (b) quite a few proposed the three rings were joined by two phenol oxidative couplings. This is not the most plausible biosynthesis but is conceivable, so they could still get most of the marks. However, a biosynthesis of phenol would be required and many struggled with this. The correct answer, dimerization of two C_6-C_3 units via a double Claisen condensation, was much easier.

Paper 2 – questions are marked out of 25

Q.18. (Advanced polymer chemistry) 21 scripts. Average 16.1/25, Range 9 to 25.
(a)The students had a good idea of block co-polymers and the types of end-groups that were present. Most students were able to identify and draw a simple block co-polymers.
(b) Very few students were able to calculate the DP of a polymer at a given %conversion.
(c) In general students had a good idea that the Tg of a random vs a block co-polymer were difference and a good amount of them were able to recollect the formula for the weighted average Tg of a random copolymer.
(d) The students struggled slightly on being able to discuss how a manipulation to a structure would affect a Tg, but most were able to offer that greater flexibility would

probably lower the Tg. However, a large amount of students made simple mistakes on drawing the structure of a reduced carboxylic acid.

(e) Most students had a good idea that crosslinking a structure could lead to an elastomer and were able to reproduce the stress/strain curves.

(f) Most students were able to offer sensible mechanisms for ozonolysis.

Overall the students overall at a good level in this course.

Q.19. (Advanced polymer chemistry) 11 scripts. Average 16.9/25, Range 7 to 23.

(a) ca. 35% of the students did not understand that polymerisation of lactide is a ring opening polymerisation and tried to invoke a radical mechanism!

(b) a few alternative, far-fetched syntheses, but most got this part correct as it was directly discussed in notes/class.

(c) most got it right and noticed that lactide is a dimer of lactic acid.

(d) almost all got this part correct.

(e) some did not recall what ethylene oxide was and tried a radical mechanism; only a few were able to think about assembly of block copolymers into micelles (although this should have been readily achievable from class notes).

Overall a good average was achieved which demonstrates the students overall performed at a good level in this course.

Q.20. (Inorganic materials) 21 scripts. Average 16.2/25, Range 11 to 22.

This question was well answered. Areas that caused frequent problems were difficulty in assessing the degree of anisotropy in the absence of a T ground term. Many candidates calculated the size of the inversion barrier in (d)(i) wrongly because of either a failure to recognise that the top of the energy manifold has m_s = +/- ½, or incorrectly determining the spin ground state.

Q.21. (Inorganic materials) 9 scripts. Average 15.7/25, Range 10 to 22.

Only one candidate tried to show how formate could act as a bridging ligand, but they got the correct answer. Some of the answers to (b) and (c) weren't well structured, so missed some important points leading to failure to identify canted antiferromagnetism. In part (e), having identified that Mean Field Theory should work for Mn^{2+}, no candidate commented on the deviation between the ordering temperature and the Weiss constant.

Q.22. (Bio-inorganic chemistry) 13 scripts. Average 17.6/25, Range 14 to 23.

This question was re-marked to bring the average down. Principally part (a) (i) was marked more harshly, expecting more detail for full marks.

(a) (i) Mechanism reproduced well. Part (ii) surprisingly most students missed the point, which simply required noting the Fe=O group would be too far from substrate binding site in structure drawn. Only 3 scripts noted this and only one gave the sensible answer that the aKG could bind in different coordination sites. Part (iii) was done very well, with good rational for choice of most likely mechanism.

(b) 5 marks for mechanism and 5 for use of clues. Most scripts got the mechanism correct or close, but few described how information was used. Only one deserved full marks for this, but good spread of marks overall so was a good discriminator.

Q.23. (Bio-inorganic chemistry) 11 scripts. Average 15.3/25, Range 7.5 to 20.5.
An incomplete script that got a mark of 7.5 took the average from 16.1 to 15.3.
(a) Recall part of questioned exposed some students' understanding of the difference
between setting reduction potential and lowering activation energy for electron transfer.
Choice of examples of protein was not always sensible, but in general done OK, if too many
words used.
(b) Overall, the only difficult part of this question was part (ii) which required coming up
with a simple relationship between the different enthalpic quantities provided. About half
couldn't do this. It is disappointing how many students simply don't understand the
behaviour of titratable groups and cannot relate numbers of protons released or taken up
with pKa/pH values. A 'primer' on this would be a good idea. One slight ambiguity was
raised in part (iii). It might have been better to point out that the pKa values provided for
the histidine ligands are in the absence of the metal ion.

Q.24. (Soft matter – from molecules to materials) 23 scripts. Average 17.3/25, Range 9 to
23.
The question was mostly well answered. Most students could give good definitions and
explanations of the concepts as required. The final numerical question was also in general
well answered.

Q.25. (Soft matter – from molecules to materials) 29 scripts. Average 16.4/25, Range 10.5 to
22.5.
This question was generally well answered, with many candidates showing good
understanding of the topics in this subject. Some well prepared candidates were able to
score very highly. A smaller number of candidates appeared to be inadequately prepared, in
terms of not having covered sufficiently the entire breadth of the subject. Common errors
included: (i) candidates using the wrong expression for the electrophoretic mobility (wrong
pre-factor), as well as (ii) forgetting to divide the micelle concentration by the aggregation
number to obtain the proper number concentration.

Q.26. (Energy landscapes and soft matter) 9 scripts. Average 15.4/25, Range 9 to 21.
This question was not difficult although some care is needed in (c,d), where several
candidates made algebraic mistakes. Most candidates appreciated the key points, that high
entropy is achieved in states where particles are free to move (large cells). However,
explanations and derivations were not always precise enough to get full credit.

Q.27. (Energy landscapes and soft matter) 7 scripts. Average 19.4/25, Range 16 to 22.
Answers ranged from decent to very good. All the candidates were able to do the first easier
parts, and most managed the t_{obs} mean first passage time. A couple of the disconnectivity
graphs were wrong. For the last part, several candidates manged to extract the correct time
scales from the graph. The others were generally able to say what the steps corresponded
to.

Q.28. (Stereocontrolled organic synthesis) 38 scripts. Average 14.0/25, Range 6.5 to 19.5.
Overall, this question appeared to be accessible to the majority of students. Most students
identified in part A that the Evans-Saksena reduction was required to achieve the correct

stereochemical outcome; however, few students remembered the correct conditions required. While many included the correct transition state model, explanations of why both the reducing agent and acid were required were rare. Almost all students found part B accessible, with almost all achieving full marks for the correct Evans asymmetric aldol model. The following epoxidation proved more problematic, while many students identified H-bonding to the allylic alcohol, few reasoned that H-bonding to the silyl-protected alcohol could also drive selectivity, although pleasingly many students correctly used the Houk model in their explanation. The final question clearly stretched many students. Pleasingly, many students identified the correct intermediate following epoxide opening and trans-selective reduction of the alkyne. While a handful of students identified that the reaction was a Prins-cyclization, many didn't identify trifluoroacetate as the nucleophile.

Q.29. (Stereocontrolled organic synthesis) 13 scripts. Average 17.1/25, Range 7 to 25.
(a) Generally quite good answers. The behaviour of the sulphonium species was described well and its interaction with the second starting material. The rearrangement required to get to the final product was not found by everyone. Some people benefitted by working backwards from the answer after getting lost going forwards
(b) The sequence (Mitsunobu, methanolysis, Claisen, ionic reduction) are all close to examples in the lectures, but the question is made harder by stringing four processes together. There were good accounts of the individual transformations and many people gave a reasonable pathway to the final product
(c) Hard question. Various possible sequences are reasonably plausible and were given credit. Analysis of the stereochemistry of the product is an important part of the question.

Q.30. (Computer simulation methods) 1 script. 10/25.
In part (a), the potential energy has not been computed, however distances between different amino acids have been measured, and the amino acids interacting through Periodic boundary conditions have been identified. In part (b), the temperature of the system has not been properly evaluated. It seems that the wrong use of units has led the candidate to a wrong estimate of the temperature, 20 orders of magnitude lower than the actual one. Part (c), has not been done since part (a) results were missing, and part (c) entailed combining results from both parts (a) and (b). Part (d) was discussed properly. Part (e) (i) was not done, and Part (e) (ii) was incorrect. Again a problem with units is the cause of the wrong result.

Q.31. (Computer simulation methods) 6 scripts. Average 20.25/25, Range 14 to 24.
Most students answered the question at a very high level, specially the first part of the question where the students had to write a pseudo code for Monte Carlo simulations. Most minor problems occurred in the final parts of the questions, where the students had to draw distributions of their outputs of hypothetical simulations ran with their codes.

Q.32. (Main group organometallics) 24 scripts. Average 15.7/25, Range 4 to 23
The question was pretty reasonably done and required no moderation. The main area where there seemed to be difficulty was part d, where few candidates contributed much meaningful discussion. In more detail:
(a) Generally M1 and M2 were correctly identified, though a significant minority of

candidates got the metals the wrong way round and presumably therefore missed the idea that the bigger metal can have a larger coordination sphere. Quite a few candidates also drew bridging THF rather than bridging amides.

(b) Generally done very well except that a significant number of candidates only used 'steric bulk' to explain the monomer. The lectures explicitly mention C–H···Li stabilization in ate complexes.

(c) Part (i) was generally done extremely well. The vast majority of candidates identified **C-G** and explained the cryoscopy and NMR data very well. Very few marks were lost here. For part (ii), most candidates drew appropriate structures, though a few drew ladders and where clearly thinking of pure lithium amides.

(d) This proved very challenging. Most candidates identified **H**. However, only the very strongest commented meaningfully on which two amide ligands were involved in exchange and only one or two candidates would explain how this might correlate with 3 Li centres exchanging. No candidates commented on the formation of two cuprates in solution or that both could be achieved by abstracting a common amide dimer from the (often correctly proposed) structure of **H**.

Q.33. (Main group organometallics) 5 scripts. Average 18.4/25, Range 11.5 to 23.

(a) This was a straight recall of material from the lecture notes and was universally answered well, with all candidates providing the appropriate MO diagram. All understood the changes in bonding upon changing the metal, though not all discussed the effects of different types of ligands (alkyl vs. pi-donors).

(b) This simply involved recognising the number of electrons contained in different types of orbitals and summing the values to obtain magic numbers. Not all candidates went through the whole series or calculated them correctly.

(c) These were all examples of clusters seen in the lectures, though they had not all been electron-counted. Most candidates were able to give the correct electron counts by identifying the isolobal fragments contributing to total cluster electron count.

(d) Most of the marks in this question were redistributed to the more involving part (e). Marks were awarded for the correct structure and partial marks for assigning any of the NMR peaks.

(e) Most candidates predicted a sensible structure based on the NMR data. The full marks were given if the structure was sensible and fitted the NMR data (e.g. interstitial hydride rather than face-capping). The application of Wade's Rules was not dependent on knowing the previous structure, rather a matter of counting electrons contributed from isolobal fragments. Most could do this correctly though some miscounted on the number of electrons contributed by different fragments. The final part required candidates to also find a way to increase the electron count and the top students recognised the involvement of C=C pi-bonding into the cluster to provide two additional cluster bonding electrons per C=C double bond.

Q.34. (Aromatic heterocycles and medicinal chemistry) 33 scripts. Average 15.9/25, Range 9.5 to 22.

This question proved relatively unpopular for an M9 question without any medicinal chemistry in it – for the past two years the 'med-chem' question has attracted considerably

fewer attempts than the straight heterocycles question, but this year the reverse was true. Evidently Q35 appeared to be (and in retrospect probably was) the easier of the two M9 questions on paper 2.

(a) Most people could deduce the structure of the heterocycle, but mechanisms to get to it were often rather sloppy. There was a great deal of confusion over the role of the P_4O_{10}, with suggestions including an oxidising or reducing agent, or a source of 'O' analogous to the use of P_4S_{10} to replace oxygen with sulfur.

(b) A range of mechanisms was seen here, varying in their degree of plausibility. Not everyone drew mechanisms for the formation of both products, and marks were also lost for careless mechanism errors such as missing curly arrows, missing charges, inappropriate protonation states, and so on.

(c) **C** to **D** was a standard Hantzsch thiazole synthesis followed by triflation ready for a Sonogashira coupling, and many candidates were able to make some good progress although some did not make the thiazole in step (i) and then used the Tf_2O to complete the thiazole synthesis, often with some unlikely carbonyl substitution steps. Some candidates thought that the Br needed to remain on the molecule in order for it to be able to take part in a cross-coupling reaction.

In the **E** to **F** step, the esterification (step (i)) appeared to cause some considerable confusion. $ArSO_3H$ was there simply as an acid catalyst (in fact TsOH was used) but several candidates seemed to misread it as mCPBA and tried to do various reactions with it such as oxidising the thiazole sulfur to a sulfoxide. Others had it forming a mixed anhydride with the carboxylic acid prior to the ester formation. Among those who recognised acid-catalysed esterification (or Fischer esterification as several candidates noted) the standard of mechanisms was very poor for what should have been a IA level reaction: it was not uncommon to see S_N2 at the carbonyl, hydroxide as a leaving group (despite the acidic conditions), or for the OH of the carboxylic acid to be protonated as the first step (prior to nucleophile attack) rather than the carbonyl. The Huisgen triazole synthesis in step (ii) was more successfully answered.

The **F** to **G** step was generally well answered, although several candidates used the KOH in the first step to hydrate the alkyne to form an enol (or ketone) rather than simply hydrolysing the ester. **G** to **H** proved difficult, with very few candidates successfully predicting the conversion of the pyrone into a pyridone. Many simply turned the carboxylic acid into an amide (unlikely under these conditions, as emphasised in IA, as the ammonia would simply deprotonate the carboxylic acid rather than attack it). A variety of other proposed products was also seen. Credit was awarded for any sensible chemistry.

Q.35. (Aromatic heterocycles and medicinal chemistry) 46 scripts. Average 16.1/25, Range 7 to 22.5.
This question was a popular one and was generally well answered so that some harsh marking was needed to achieve the target average.

(a) Most candidates produced some good answers here. Where marks were lost it was generally for not including enough detail or being specific enough, for example making general statements about binding rather than referring specifically to the molecule in question and to the crystal structure schematic given in the question. Many candidates

talked a lot about how adjusting the electron density in the benzene ring of the R_3 substituent might affect its pi stacking ability, although in fact (and as a few candidates noticed) the results from compounds **I** and **J** indicate that both electron withdrawing and electron donating substituents could give similar binding affinity.

(b) Again well answered, with most marks lost for being too vague or not giving enough detail. In part (ii) it was more common to focus on metabolism and elimination than on absorption, despite the fact that (as some candidates noted) this was a cell-based assay rather than an in vivo study and the cells involved were (probably) not liver cells. Nevertheless, all plausible suggestions received some credit.

(c) The effect of the ester substituent on the regioselectivity of the pyrrole acylation was well known and most candidates predicted the correct structure for **K**. A few did not actually draw the structure of their final product, instead writing 'TM', which is not really the point of a question that asks for the product to be predicted. Part (ii) was potentially challenging, as candidates had to realise that the thiol needed to be turned into an electrophile for the pyrrole to attack it. Nevertheless, there were a lot of good answers as well as a few featuring rather more exotic/unlikely chemistry. Part (iii) was generally well answered, with most candidates recognising some sort of van Leusen / Barton–Zard reaction although many showed a tendency to skip steps in their mechanism.

Paper 3 – questions are marked out of 25

Q.36. (Catalysis in synthesis) 32 scripts. Average 16.3/25, Range 10 to 23.
The four different components attracted a range of answers such that the candidates could be adequately differentiated. For part (a) small majority of the candidates saw that this was a variation on a Stille coupling and the most accessible C-Br bond underwent selective oxidative addition. In part (b) a variety of mechanisms were offered to get to **C** and appropriate credit was given for reasonable and plausible answers. In part (c) the hydrozirconation reactivity was well spotted but there was significant variation in how the candidates handled the stereochemistry of this and the subsequent cyclisation. In part (d) the clue about beta carbon elimination was generally well acted on and candidates generally did a good job of figuring this mechanism out.

Q.37. (Catalysis in synthesis) 19 scripts. Average 16.2/25, Range 8 to 22
The four different components attracted a range of answers such that the candidates could be adequately differentiated. For part (a) a small majority of the candidates saw that this was a straight forward double epoxidation. Most got the mnemonic correct but there were some mistakes in applying it. In part (b) the straight forward proline aldol part was generally answered well and what differentiated candidates is how they dealt with the second type of chirality that was introduced in the product during the reaction and appropriate credit was given for reasonable answers. In part (c) the quadrant diagram of S-BINAP was generally well applied and what differentiated candidates is how well they fit the substrate into this and also applied the hydroacylation mechanism, for which they were given the clue of how to start. In part (d) there were a range of answers and appropriate credit was given for plausible answers.

Q.38. (Electronic structure of solid surfaces) 23 scripts. Average 16.8/25, Range 9.5 to 21. The majority of candidates answered the question well, with 18 earning between 16.5 and 21. This was generally because they found parts (a) to (d), relating to the use of a CHA, straightforward, calculating the required numerical answers correctly, and therefore obtaining a very high proportion of the 16 marks available. In part (e), candidates were asked to "Explain, as fully as possible…". Most candidates correctly ascertained that the molecule lies flat (or close-to flat) on the surface, but emphasis in the marking was given to the detail and clarity in the explanation of the underlying theory, meaning the average mark was around 3 out of 6. The final part of the question was rather poorly answered: candidates missed the development of the shoulder at 400.1 eV at 320 K (not present at 300 K according to the text) and did not provide explanations that were consistent with the evolution of the spectrum, although most made comments that were worthy of some credit.

Q.39. (Electronic structure of solid surfaces) 17 scripts. Average 15.3/25, Range 7 to 21. Part (a) was generally well done with most getting the effective mass. Part (b) was identified as IPES by approximately half of the cohort, and credit was given for stating the difference with UPS in terms of occupied and unoccupied levels. Part (c) had a mixed reception with a good number correctly obtaining the effective mass and Emin, but not making the connection that the effective mass was that of the free electron nor that this looked like an image state. Part (d) had a range of answers and credit was given for sensible comments about projection of bulk states/visibility of surface states. Most candidates correctly could explain the form of the features with most giving a clear series of diagrams as an effective explanation. Most also correctly identified the CH bands, but only a few considered frustrated modes and surface involved modes. Almost all correctly identified that H containing modes would move, most said the movement would be in the correct direction, although one or two suggested a shift in the opposite sense.

Q.40. (Chemical biology and drug discovery) 34 scripts. Average 16.2/25, Range 11 to 20. This question was well answered. I was expecting students to develop more on why cysteine is an ideal residue to achieve homogenous conjugates in part (a). All parts of (b) were overall well answered. The students clearly had got a good understanding of how an antibody-drug conjugate works and the pros and cons of the current bioconjugation strategies to build them, as well as the mechanisms of self-immolative linkers.

Q.41. (Chemical biology and drug discovery) 27 scripts. Average 16.4/25, Range 8 to 22. Overall this question was answered well and I was happy with how the question was answered. Part (a) was answered well as was part (b) which applied what was outlined in the lectures. Part (c) of the question proved more challenging but good attempts were made at the question. Part (d) of the question proved challenging with the mechanism of ring opening of the furan from the attack on the extended conjugated system but good attempts were made at the mechanism. The script that obtained the lowest mark was due to poor mechanisms for the questions including those mechanisms that were covered in lectures.

Q.42. (Solid electrolytes) 12 scripts. Average 14.5/25, Range 8 to 21.
This question was on the use of NMR, and in particular the spin-lattice relaxation time, T_1, to probe ionic diffusion in solids. It ranged from exploring more fundamental aspects to an estimation of the diffusion coefficient for F-ion diffusion in BaF_2. The response of the candidates was very bimodal: slightly more than half answered the question very well (average mark = 18/25), while the remainder did very poorly (average = 10/25). No-one used knowledge of the given fluorite-type structure of BaF_2 to correctly identify the ion-jump distance.

Q.43. (Solid electrolytes) 13 scripts. Average 18.7/25, Range 4 to 25.
I presume that students with a strong theoretical background attempted the question and thus the mean mark is high. This question did not cause many difficulties for the majority of candidates with three full marks achieved. Parts (a) and (b)(i) were very straightforward and were answered correctly without any problems. In part (b)(ii), several candidates gave the answer for the conductivity tensor in the form of the scalar product rather than in components. In part (b)(iii), some of the candidates calculated incorrectly the sum over nearest neighbours and thus obtained wrong results. Parts (b)(iv) and (b)(v) were answered correctly by the majority of candidates.

Q.44. (Supramolecular chemistry) 18 scripts. Average 15.3/25, Range 7 to 24.
Most had a sense of which metal should bind best in part (a), and the logic used in justifying the choice presaged how well the other parts would be answered. In part (b) some students got the right answer even though the wrong binding hierarchy was inferred; generous partial credit resulted. Most got the logic of part (c) right, although a few neglected to discuss alternative spectroscopic methods, thus losing a few marks. In part (d) the key features were a very rapid rise and then exponential decay - partial credit was given in cases where these features were not explicitly noted.

Q.45. (Supramolecular chemistry) 17 scripts. Average 16.2/25, Range 7 to 25.
For part (a), most got the imine condensation right, but a sizable minority thought that **3** had an Fe_4L_4 tetrahedral structure, which would have been entropically disfavoured. Most got part (b) right, although a few thought that dppp might be displaced. The discussion of chirality in (c) revealed fuzzy thinking on several occasions; full marks required a discussion of racemic and *meso* possibilities. Most likewise got part (d), although those who missed the structure of **3** had trouble here. The chirality discussion in (e) was also enlightening, with several getting the point group 'O' correct, but asserting that it was achiral! Part (f) was likewise sensibly answered by most, although most also missed full marks for either not noting that both **3** and **4** were products, or by not providing the correct stoichiometric ratio between these products.

Q.46. (Chemical Dynamics) 9 scripts. Average 19.7/25.
This question was very well answered on the whole. All candidates obtained full marks for parts (a)(i)-(iii). Marks were lost on (iv) for small errors in the derivations and wave function sketches. (a)(vi) was one of the less well answered parts, with candidates forgetting the simple relation between the reaction probability and thermal reaction rate. Part (b)(i) was

very well answered; candidates lost marks in (b)(ii), mainly for lack of time to complete/algebraic errors.

Q.47. (Machine learning) 4 scripts. Average 16.8/25, Range 16 to 18.
All four answers for this machine learning question were decent. Some of the candidates did not make their working very clear and did not simplify the solutions to the mathematical parts. The diagrams would all have benefited from using a ruler.

Q.48. (Total synthesis) 19 scripts. Average 16.5/25, Range 7.5 to 23.5
On the whole, it seems that the target average was obtained without too much trouble. Again, few excellent scripts but also only a small number of poor ones.
(a) Generally ok, although it seems some people can't remember a mnemonic.
(b) Only one person got this one right. Clearly the Payne rearrangement was not spotted by most, but as a result many came up with rather implausible suggestions just so they could get to the given product.
(c) Generally ok, although few picked up strain release as a potential driving force.
(d) Generally ok.
(e) Generally ok.
(f) On the whole, I was pleasantly surprised that they got the radical parts of this right considering there is no formal radical component of the course at Cambridge.

Q.49. 20 scripts. Average 16.6/25, Range 10.5 to 22.5.
The average mark was reached without any trouble. Generally ok, although many answered the simple parts poorly.
(a) clearly caught many people out. I was very lenient here, but too many people had chemically incorrect routes. A few did very well. Generally average
(b) remarkable how few people got this right considering it was a DA reaction. This was pretty much an answer they could have got from their notes
(c) generally no problems here
(d) mostly fine although there were a few aberrations.
(e) generally ok
Again, not too many great scripts but only one or two poor ones.

Q.50. (Biosynthesis) 11 scripts. Average 16.0/25, Range 12 to 20.5.
This proved a good question giving about the right average without needing to be harsh or lenient in the marking. Both (a) and (b) started with deliberately easy parts. For **F** to **G** one or two got the initial Cope rearrangement but no-one got the subsequent Diels-Alder (though a few were close and got almost full marks). Most could see which bonds needed to be made and broken and got marks even for that. In formation of **C** most did imine formation and E2 elimination of phosphate, which only got half marks - the correct mechanism migrates the imine double bond to make an adjacent ketone and then the elimination is E1cb (then the double bond has to migrate back again).
   In (b) most gave good mechanisms for forming **J** but a lot of these did not get the late-stage Wagner-Meerwein rearrangement needed to make **I**.

Q.51. (Biosynthesis) 3 scripts. Average 17.3/25, Range 14 to 21.5.

One very good answer and two average ones. The average ones were not careful enough and made mistakes in drawing the initial natural product which caused further mistakes later on. Also, they did not get that methoxymalonyl CoA (derived from glycerol) is the precursor for extension modules 5 and 11. In (g) there were two possible acceptable answers based on either the stereochemistry of the Me group or the stereochemistry of the -OH; only one of the three got either of these correct.

Paper IDP1 – questions are marked out of 25

IDP1 Q1. 30 scripts. Average 16.6/25, Range

A lot of good answers and no poor ones. The photolysis calculation was done very well by all candidates. While some candidates combined the tropospheric and stratospheric lifetimes correctly in the calculation of the GWP, some used just the stratospheric lifetime and accordingly got far too high a GWP. Some recognised that loss of the replacement gas was dominated by tropospheric loss and used the tropospheric lifetime, which gave a much better answer.

   The discussion of GWP as a metric – based on the lecture notes - was rather up and down.

IDP1 Q2. 24 scripts. Average 16.7/25, Range

Most candidates answered the first three parts of the question well. However, many had issues with the rather complicated (too complicated?) differentiation required to find the temperature dependence – and allowance for this was made in the marking. The final part of the question wasn't answered particularly well; many candidates ignored the instruction to discuss the temperature dependence of the reactions or failed to address the temperature dependence of the termolecular reaction.

IDP1 Q3. 24 scripts. Average 16.4/25, Range

Candidates showed generally good knowledge of the roles of NOx and VOCs in ozone production and loss in the troposphere. The aerosol indirect effects were also covered well. However, nearly all the candidates assumed that the reaction $O_3 + h\nu = O(1D) + O2$ constituted a nett loss process for ozone in the troposphere and did not recognise that most O(1D) is recycled back to ozone.