A Statistical Analysis of the Effect of Catalysts on the Oxidation of Alkenes Using spinel ferrites.

IB Chemistry HL

Big topic!

this needs to be added

A deep analysis of a specific peer-reviewed paper with new data treatment.

Research Question:

What is the effect of different catalysts on the oxidation of alkenes?

Introduction:

Personal Engagement:

The idea for this investigation came from learning about the significance of catalysts in the existence of chemical reaction during the unit of chemical kinetics. Later, when learning about organic chemistry, and alkenes, the research question and methodology for this investigation solidified.

Relevance:

This topic is relevant and significant because the oxidation of alkenes is an important method for the synthesis of chemical intermediates in the manufacture of high-tonnage commodities, high-value fine chemicals, agrochemicals and pharmaceuticals.[1] Oxidations are often inefficient, however the results derived from this study addresses improving the efficiency, by catalysts, of the oxidations.

Environmental and Ethical Concerns:

A new challenge to be addressed in green chemistry is the creation of new methods and technologies for catalyst recycling to replace traditional conventions, this study is significant because there is an emphasis on the use of magnetic metal oxides nanoparticles as easily recycled, heterogenous, and magnetically-recoverable catalysts for the oxidation of various alkenes in the presence of *t*-BuOOH as oxidant.

Background:

Alkenes are a family of hydrocarbons (compounds containing carbon and hydrogen only) containing a carbon-carbon double bond. The first two are: ethene (C_2H_4) and propene C_3H_6. All the alkenes that contain 4 or more carbon atoms show structural isomerism, meaning there are two or more different structural formulae that you can draw for each molecular formula.
For example, with C_4H_8, three structural isomers can easily be derived:[2]

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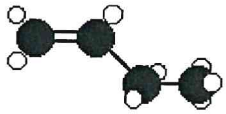
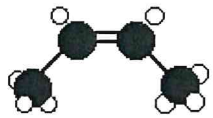
[1] Kooti, M., and M. Afshari. "Magnetic Cobalt Ferrite Nanoparticles as an Efficient Catalyst for Oxidation of Alkenes." *Scientia Iranica* 19, no. 6 (May 1, 2012): 1991-995. doi:10.1016/j.scient.2012.05.005.

[2] Clark, Jim. "Introducing Alkenes." An Introduction to Alkenes. August 2015. Accessed April 10, 2019. https://www.chemguide.co.uk/organicprops/alkenes/background.html.



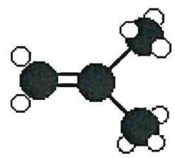
$CH_2=CH-CH_2-CH_3$

but-1-ene



$CH_3-CH=CH-CH_3$ (cis + trans)

but-2-ene



CH_3
$CH_2=C$
CH_3

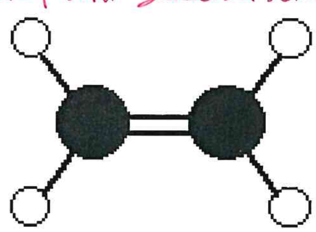
2-methylpropene

interesting.

The boiling point of each alkene is very similar to that of the alkane with the same number of carbon atoms. Ethene, propene and the various butenes are gases at room temperature. All the rest are likely liquids. In each case, the alkene has a boiling point which is a small number of degrees lower than the corresponding alkane. The only attractions involved are Van der Waals dispersion forces, and these depend on the shape of the molecule and the number of electrons it contains. Each alkene has 2 fewer electrons than the alkane with the same number of carbons. Alkenes are virtually insoluble in water, but dissolve in organic solvents.

To understand the bonding in alkenes one can observe ethene, because what is true of C=C in ethene will be true of C=C in more complicated alkenes. Ethene is modeled below:

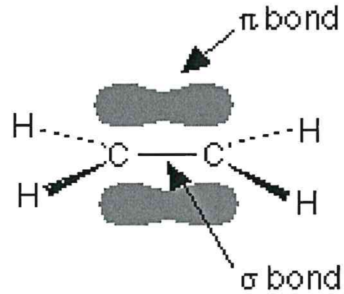
not true... at some point they will become solids.



The double bond between the carbon atoms is two pairs of shared electrons. The two pairs aren't the same as each other. One of the pairs of electrons is held on the line between the two carbon nuclei, and the other is held in a molecular orbital above and below the plane of the molecule.[3]

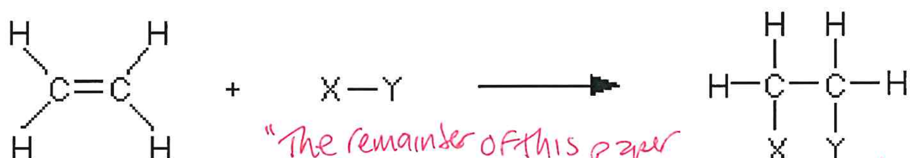
Well said. $\sigma + \pi$

[3] Clark, Jim. "Introducing Alkenes." An Introduction to Alkenes. August 2015. Accessed April 10, 2019. https://www.chemguide.co.uk/organicprops/alkenes/background.html.



In the diagram above, the line between the two carbon atoms represents a normal bond or the pair of shared electrons lies in a molecular orbital on the line between the two nuclei, called a sigma bond. The other pair of electrons is found somewhere in the shaded part above and below the plane of the molecule, called a pi bond. The electrons in the pi bond are free to move around anywhere in this shaded region and can move freely from one half to the other. The pi electrons are not as fully under the control of the carbon nuclei as the electrons in the sigma bond and, because they are exposed above and below the rest of the molecule, they are open to attack by other entities.

Similar to other hydrocarbons, alkenes burn in oxygen, however these reactions are insignificant. Alkenes are too valuable to utilize in this manner. Significant reactions are based on the double bond. Generally, the pi bond breaks and the electrons from it are used to join the two carbon atoms to other things. Alkenes undergo addition reactions, demonstrated below using a general molecule X-Y:



The exposed electrons in the pi bond are open to attack by entities which carry a degree of positive charge, called electrophiles.[4]

Spinel ferrites, with the general formula of MFe_2O_4, M being a divalent cation, provide more interesting catalytic activities compared to the related single component metal oxides and are regarded as one of the most important inorganic nanomaterials because of their electronic,

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[4] Clark, Jim. "Introducing Alkenes." An Introduction to Alkenes. August 2015. Accessed April 10, 2019. https://www.chemguide.co.uk/organicprops/alkenes/background.html.

it needs to be mentioned what a catalyst is (a substance that inc. rate but is not consumed)
are these catalysts used to oxidize alkenes?

optical, electrical, magnetic and catalytic properties, all of which are different from their bulk counterparts.[5] OK that seems sort of random. ..

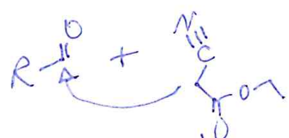
Previous Experiments: Practical information, OK - But how do they function? what is the mechanism?

In the past, Fe_3O_4 and γ-Fe_2O_3 have been used as catalysts, but compared to $CoFe_2O_4$, show some drawbacks. Fe_3O_4 can be easily prepared and has been efficiently used in several organic reactions, however it is reactive to acidic and oxidative environments. Also, γ -Fe_2O_3 is also not thermally stable. On the other hand, $CoFe_2O_4$ nanoparticles have a strong chemical stability and have been used in various fields, but few efforts have been focused on its catalytic activity in organic reactions. OK

Senapati et al. used a $CoFe_2O_4$ nanocatalyst (40–50 nm) as an efficient catalyst for a Knoevenagel condensation reaction of various aldehydes with ethylcyanoacetate. They were able to recover the catalyst from the reaction mixture with the assistance of an external magnet. Additionally, aerobic oxidation of cyclohexane to cyclohexanol or cyclohexanone was also reported to be catalyzed by magnetic $CoFe_2O_4$ nanocrystals in solvent free conditions. Lastly, the decomposition of methanol to H_2 and CO was studied by Manova et al. using nanosized iron and iron–cobalt spinel oxides as catalysts.[6]

this should be described
isn't this outside the scope of this paper? It's not an alkene oxidation.

Methodology:


Knoevenagel

Summary of Experiment:

1. Co-precipitation was used to synthesize cobalt ferrite nanoparticles with mean size of 25 n. ← nm?
2. Cobalt ferrite nanoparticles were used as catalysts for the oxidation of several alkenes in the presence of *t*-BuOOH as an oxidant. ✓

Oxidation of alkenes were carried out in a 25 mL flask with a magnetic stirrer and a reflux condenser. The reaction vessel was charged with: cobalt ferrite catalyst (40 mg), 1, 2-dichloroethane (5 ml), substrate (1 mmol), *t*-BuOOH (3 mmol). The reaction mixture was heated in an oil bath at 70 °C and its progress was monitored. At the end of the reaction, CH_2Cl_2 was added to dilute the reaction mixture and the liquid phase was decanted by an external

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[5] Kooti, M., and M. Afshari. "Magnetic Cobalt Ferrite Nanoparticles as an Efficient Catalyst for Oxidation of Alkenes." *Scientia Iranica* 19, no. 6 (May 1, 2012): 1991-995. doi:10.1016/j.scient.2012.05.005.

[6] Kooti, M., and M. Afshari. "Magnetic Cobalt Ferrite Nanoparticles as an Efficient Catalyst for Oxidation of Alkenes." *Scientia Iranica* 19, no. 6 (May 1, 2012): 1991-995. doi:10.1016/j.scient.2012.05.005.

magnet. The decanted solution was purified on a silica–gel plate to derive the pure product. The identities of the products were confirmed by FT-IR and H NMR spectral data.

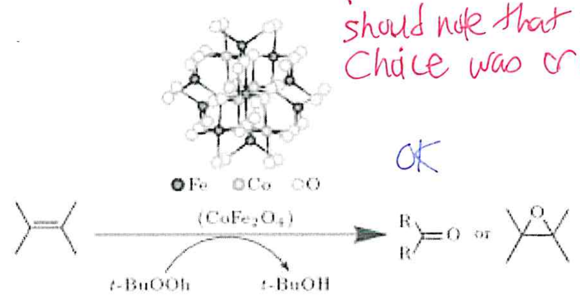
Finding the Optimal Experimental Conditions:

Styrene was the model alkene used with *t*-BuOOH as an oxidant in the presence of the cobalt ferrite catalyst. Different solvents were observed, and 1, 2-dichloroethane was found to have given the maximum styrene conversion. Table 1 presents the effect of different solvents on the oxidation of styrene, showing ~~1, 2-dichloroethane to be the most of efficient.~~ Scheme 1 demonstrates the general reaction which alkenes are oxidized using $CoFe_2O_4$ as a catalyst.

Table 1: Effect of solvent on oxidation of styrene catalyzed by $CoFe_2O_4$[a].

Solvent	Styrene conversion (%)[b]	Selectivity of benzaldehyde (%)
Acetonitrile	10	88
Chloroform	65	55
1,2-dichloroethane	70	85
Methanol	45	53
1,2-dichloroethane/methanol (1:1)	55	68

[a] Reaction conditions: alkene (1 mmol), *t*-BuOOH (3 mmol), catalyst (40 mg), solvent (5 ml), $t = 12$ h, $T = 70$ °C.
[b] GC yields based on starting alkenes.



Scheme 1: Oxidation of alkenes using $CoFe_2O_4$ catalyst.

In terms of testing different oxidants, *t*-BuOOH was designated as the best source of oxygen after observing H_2O_2 and H_2O_2/Urea. And hydrogen peroxide could not be used as an oxidant, because it decomposes in the presence of the cobalt ferrite catalyst.

In regard to selecting the optimal reaction time, the influence of reaction time on the styrene conversion and product selectivity was tested, as demonstrated by Figure 4.

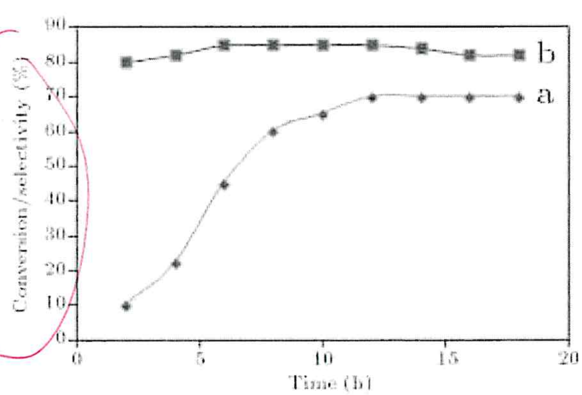


Figure 4: Effect of reaction time on (a) styrene conversion and (b) product selectivity over $CoFe_2O_4$ catalyst.

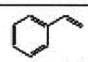
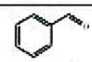
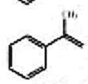
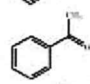
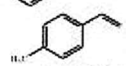
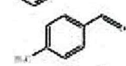
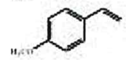
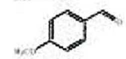
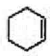
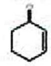
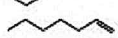
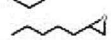
At 12 h, styrene conversion increases up to 70 mol %, while the selectivity of benzaldehyde is 85 mol %. If the same reaction was run for 18 h, little increment is observed in styrene conversion

and product selectivity. As a result, the time of 12 h was selected as an optimized reaction time for this reaction.

Data:

Under the optimized conditions that were obtained for the oxidation of styrene, several alkenes such as a-methylstyrene, 4-methoxystyrene, 4-nitrostyrene, cyclohexene and 1-heptene were oxidized. The results are shown in Table 2: *I wonder how this compares to conventional methods.*

Table 2: Oxidation of some alkenes by t-BuOOH catalyzed by $CoFe_2O_4$[a].

Entry	Alkenes	Product	Conversion (%)[b]	Selectivity (%)	Time (h)
1			70	85	12
2			85	90	8
3			82	85	12
4			85	80	12
5			75	90	12
6			50	95	18

[a] Reaction conditions: alkene (1 mmol), t-BuOOH (3 mmol), catalyst (40 mg), 1,2-dichloroethane (5 ml), $T = 70$ °C.
[b] GC yields based on starting alkenes.

Table 3: Comparison of the oxidation of styrene catalyzed by $CoFe_2O_4$ with other similar catalysts recently used for this reaction.

Entry	Catalyst	Oxidant	Time (h)	Styrene conversion (%)	Selectivity of benzaldehyde (%)	Reference
1	$CaFe_2O_4$	H_2O_2	18	38	91	[33]
2	$ZnFe_2O_4$	H_2O_2	12	26.1	50.4	[34]
3	Fe_3O_4	H_2O_2	12	36.5	68.4	[34]
4	$NiFe_2O_4$	H_2O_2	12	31.4	55.6	[34]
5	$SrFe_2O_4$	H_2O_2	18	51	63.7	[35]
6	$NiFe_{0.4}Gd_{1.6}O_4$	H_2O_2	6	55.8	100	[36]
7	$Mg_{0.4}Fe_{2.6}O_4$	H_2O_2	12	32	63.2	[37]
8	Fe_2O_3	H_2O_2	5	19	100	[38]
9	$CoFe_2O_4$	t-BuOOH	12	70	85	This work

this is my favorite decent yield an 100% selective. *Best*

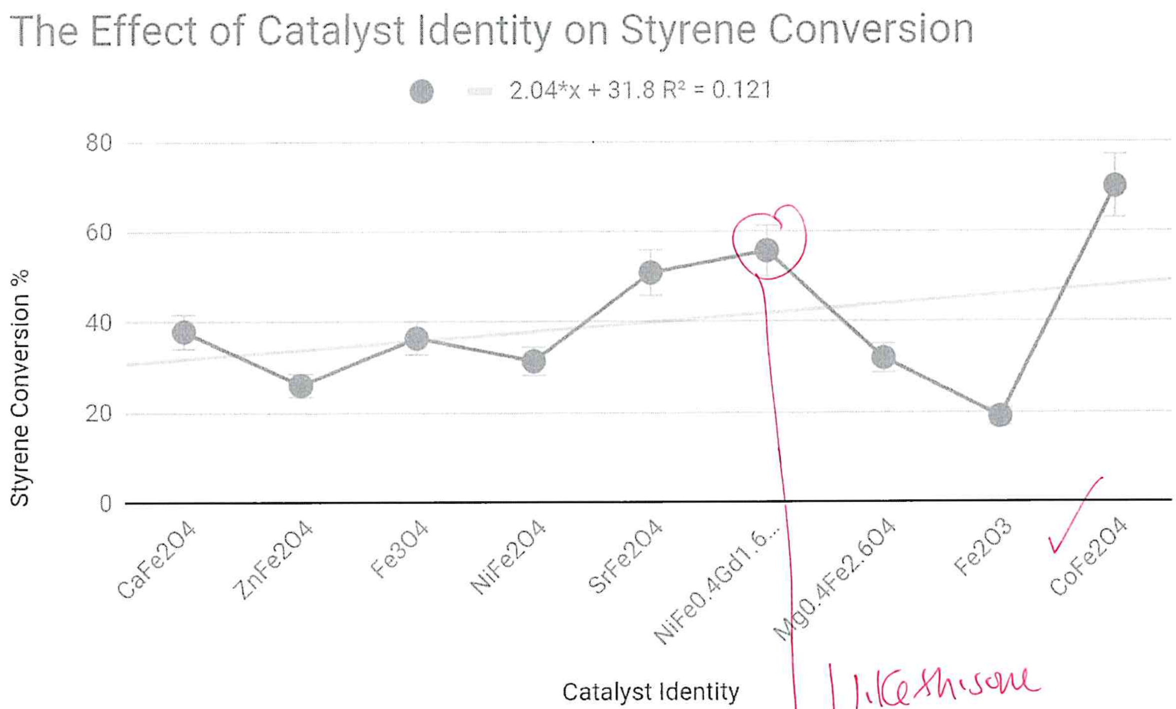
Table 3 compares the oxidation of alkenes by $CoFe_2O_4$ with other catalysts.

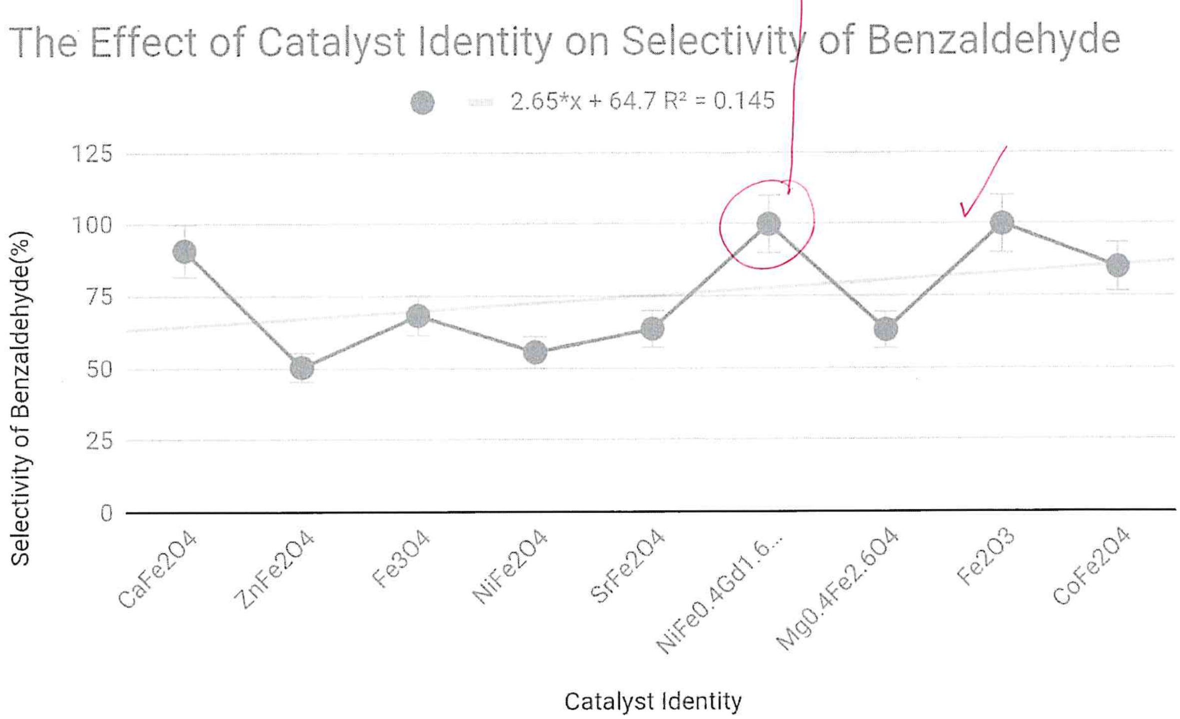
Data Processing:

From Table 2, with styrene and its derivatives, the products were the related carbonyl compounds with high yield and selectivity, identifying $CoFe_2O_4$ as an effective catalyst for the oxidation of alkenes.

From Table 3, a graph demonstrating the effect of catalyst identity on styrene conversion (%) was created. The trend line and R^2 value was calculated, and 10 % error bars were designated, identifying $CoFe_2O_4$ as the most effective catalyst for the oxidation of alkenes. Additionally, a graph demonstrating the effect of catalyst identity on selectivity of benzaldehyde (%) was created. The trend line and R^2 value was calculated, and 10 % error bars were designated, revealing $CoFe_2O_4$ to be a strong catalyst for the oxidation of alkenes.

This is you, not paper guys. *with good but not great selectivity.*





Data Uncertainty:

When comparing the effectiveness of different catalysts on the oxidation of styrene, H_2O_2 was used as an oxidant in all reactions except for the reaction in which $CoFe_2O_4$ was used as a catalyst. A change in oxidant (to *t*-BuOOH), one of the variables of the experiment, could have interfered with the oxidation of styrene, therefore it is difficult to conclude that $CoFe_2O_4$ is the most effective catalyst, as the strong results derived from the reaction catalyzed by $CoFe_2O_4$ could have been the result of the change in oxidant. Nickel doesn't have that problem.

Conclusion:

Only very low styrene conversion was obtained when the oxidation of styrene was carried out in the absence of a catalyst, with the other variables remaining constant. Therefore, the presence of $CoFe_2O_4$ nanoparticles as a catalyst is necessary for this oxidation reaction to result in high product yield. The strength and effectiveness of the cobalt ferrite nanoparticles in this oxidation reaction are explained by the high dispersity and large surface area of the catalyst providing more active sites for catalytic reaction. The Fe^{3+} ions, which are located in the octahedral sites of this ferrite, are possible active sites of the catalyst. nice.

Although this experiment produced strong results on the effect of catalyst identity on both styrene conversion (%) and selectivity of benzaldehyde (%), a wider range of both alkenes and catalysts would have allowed for a more extensive study of the effect of different catalysts on the oxidation of alkenes.

Returning to the data provided in Table 2, the oxidation of cyclohexene resulted in an allylic oxidation product, 2-cyclohexene-1-one, with 75% yield. To extend and improve this investigation, the non-activated terminal olefins such as 1-octene could be transformed into the related epoxides with good yield and high selectivity. Also, the investigation could be extended by testing the effect of different oxidants or solvents on the oxidation of alkenes.

This investigation is significant, because it reveals $CoFe_2O_4$ to be a stable, recyclable, and effective catalyst for the oxidation of alkenes. In terms of recyclability, the catalyst can be easily isolated from the reaction mixture with an external magnet. This makes cobalt ferrite an environmentally-friendly catalyst for certain organic reactions.

oh I see ... that is convenient.

Works Cited

Clark, Jim. "Introducing Alkenes." An Introduction to Alkenes. August 2015. Accessed April 10, 2019. https://www.chemguide.co.uk/organicprops/alkenes/background.html.

Kooti, M., and M. Afshari. "Magnetic Cobalt Ferrite Nanoparticles as an Efficient Catalyst for Oxidation of Alkenes." *Scientia Iranica* 19, no. 6 (May 1, 2012): 1991-995. doi:10.1016/j.scient.2012.05.005.

IB Chemistry: The Internal Assesmment (this is taken directly from the IB chemistry guide)

General introduction

The internal assessment requirements are the same for biology, chemistry and physics. The internal assessment, worth 20% of the final assessment, consists of one scientific investigation. The individual investigation should cover a topic that is commensurate with the level of the course of study.

Student work is internally assessed by the teacher and externally moderated by the IB. The performance in internal assessment at both SL and HL is marked against common assessment criteria, with a total mark out of 24.

Note: Any investigation that is to be used to assess students should be specifically designed to match the assessment criteria.

The internal assessment task will be one scientific investigation taking about 10 hours and the writeup should be about 6 to 12 pages long. Investigations exceeding this length will be penalized in the communication criterion as lacking in conciseness.

The practical investigation, with generic criteria, will allow a wide range of practical activities satisfying the varying needs of biology, chemistry and physics. The investigation addresses many of the learner profile attributes well. See section on "Approaches to the teaching of chemistry" for further links.

The task produced should be complex and commensurate with the level of the course. It should require a purposeful research question and the scientific rationale for it. The marked exemplar material in the teacher support materials will demonstrate that the assessment will be rigorous and of the same standard as the assessment in the previous courses.

Some of the possible tasks include:

- a hands-on laboratory investigation
- using a spreadsheet for analysis and modelling
- extracting data from a database and analysing it graphically
- producing a hybrid of spreadsheet/database work with a traditional hands-on investigation
- using a simulation provided it is interactive and open-ended.

Some tasks may consist of relevant and appropriate qualitative work combined with quantitative work.

The tasks include the traditional hands-on practical investigations as in the previous course. The depth of treatment required for hands-on practical investigations is unchanged from the previous internal assessment and will be shown in detail in the teacher support materials. In addition, detailed assessment of specific aspects of hands-on practical work will be assessed in the written papers as detailed in the relevant topic(s) in the "Syllabus content" section of the guide.

The task will have the same assessment criteria for SL and HL. The five assessment criteria are personal engagement, exploration, analysis, evaluation and communication.

Internal assessment component

- Individual investigation
- This investigation covers assessment objectives 1, 2, 3 and 4.

Internal assessment criteria

The new assessment model uses five criteria to assess the final report of the individual investigation with the following raw marks and weightings assigned:

2	4	6	6	3	21
2 (8%)	6 (25%)	6 (25%)	6 (25%)	4 (17%)	24 (100%)

Levels of performance are described using multiple indicators per level. In many cases the indicators occur together in a specific level, but not always. Also, not all indicators are always present. This means that a candidate can demonstrate performances that fit into different levels. To accommodate this, the IB assessment models use markbands and advise examiners and teachers to use a **best-fit approach** in deciding the appropriate mark for a particular criterion.

Teachers should read the guidance on using markbands shown above in the section called "Using assessment criteria for internal assessment" before starting to mark. It is also essential to be fully acquainted with the marking of the exemplars in the teacher support material. The precise meaning of the command terms used in the criteria can be found in the glossary of the subject guides.

Personal engagement

This criterion assesses the extent to which the student engages with the exploration and makes it their own. Personal engagement may be recognized in different attributes and skills. These could include addressing personal interests or showing evidence of independent thinking, creativity or initiative in the designing, implementation or presentation of the investigation.

0	The student's report does not reach a standard described by the descriptors below.
1	**The evidence of personal engagement with the exploration is limited with little independent thinking, initiative or creativity**. The justification given for choosing the research question and/or the topic under investigation does not demonstrate **personal significance, interest or curiosity**. There is little evidence of **personal input and initiative** in the designing, implementation or presentation of the investigation.

2	**The evidence of personal engagement with the exploration is clear with significant independent thinking, initiative or creativity.** The justification given for choosing the research question and/or the topic under investigation demonstrates **personal significance, interest or curiosity.** none of these terms were used but the student demonstrated an intimate knowledge of the specific topic There is evidence of **personal input and initiative** in the designing, implementation or presentation of the investigation. custom graphs

Exploration

This criterion assesses the extent to which the student establishes the scientific context for the work, states a clear and focused research question and uses concepts and techniques appropriate to the Diploma Programme level. Where appropriate, this criterion also assesses awareness of safety, environmental, and ethical considerations.

0	The student's report does not reach a standard described by the descriptors below.
1–2	The topic of the investigation is identified and a research question of some relevance is **stated but it is not focused**. The background information provided for the investigation is **superficial** or of limited relevance and does not aid the understanding of the context of the investigation. The methodology of the investigation is only appropriate to address the research question to a very limited extent since it takes into consideration few of the significant factors that may influence the relevance, reliability and sufficiency of the collected data. The report shows evidence of limited awareness of the significant safety, ethical or environmental issues that are **relevant to the methodology of the investigation***.
3–4	The topic of the investigation is identified and a relevant but not fully focused research question is described. The research topic (title) was not sufficiently focused, but the work was highly focused. The background information provided for the investigation is mainly appropriate and relevant and aids the understanding of the context of the investigation. alkenes yes but no background on catalysis The methodology of the investigation is mainly appropriate to address the research question but has limitations since it takes into consideration only some of the significant factors that may influence the relevance, reliability and sufficiency of the collected data. The results were not compared to conventional oxidation methods. The report shows evidence of some awareness of the significant safety, ethical or environmental issues that are **relevant to the methodology of the investigation.***
5–6	The topic of the investigation is identified and a relevant and fully focused research question is clearly described. The background information provided for the investigation is entirely appropriate and relevant and enhances the understanding of the context of the investigation. The methodology of the investigation is highly appropriate to address the research question because it takes into consideration all, or nearly all, of the significant factors that may influence the relevance, reliability and sufficiency of the collected data. The report shows evidence of full awareness of the significant safety, ethical or environmental issues that are **relevant to the methodology of the investigation.***

* This indicator should only be applied when appropriate to the investigation. See exemplars in TSM.

Analysis

This criterion assesses the extent to which the student's report provides evidence that the student has selected, recorded, processed and **interpreted** the data in ways that are relevant to the research question and can support a conclusion.

0	The student's report does not reach a standard described by the descriptors below.
1–2	The report includes **insufficient relevant** raw data to support a valid conclusion to the research question. Some **basic** data processing is carried out but is either too **inaccurate or too insufficient to lead to a valid** conclusion. The report shows evidence of little consideration of the impact of measurement uncertainty on the analysis. The processed data is incorrectly or insufficiently interpreted so that the conclusion is invalid or very incomplete.
3–4	The report includes relevant but incomplete quantitative and qualitative raw data that could support a simple or partially valid conclusion to the research question. Appropriate and sufficient data processing is carried out that could lead to a broadly valid conclusion but there are significant inaccuracies and inconsistencies in the processing. The report shows evidence of some consideration of the impact of measurement uncertainty on the analysis. The processed data is interpreted so that a broadly valid but incomplete or limited conclusion to the research question can be deduced.
5–6	The report includes sufficient relevant quantitative and qualitative raw data that could support a detailed and valid conclusion to the research question. Appropriate and sufficient data processing is carried out with **the accuracy** required to enable a conclusion to the research question to be drawn that is fully **consistent** with the experimental data. The paper that was reviewed was heavy with data + processing The report shows evidence of full and appropriate consideration of the impact of measurement uncertainty on the analysis. student extrapolated the results to re-represent the data. The processed data is correctly interpreted so that a completely valid and detailed conclusion to the research question can be deduced.

Evaluation

This criterion assesses the extent to which the student's report provides evidence of evaluation of the investigation and the results with regard to the research question and the accepted scientific context.

0	The student's report does not reach a standard described by the descriptors below.

1–2	A conclusion is **outlined** which is not relevant to the research question or is not supported by the data presented. The conclusion makes superficial comparison to the accepted scientific context. Strengths and weaknesses of the investigation, such as limitations of the data and sources of error, are **outlined** but are restricted to an **account** of **the practical** or **procedural issues** faced. The student has **outlined** very few realistic and relevant suggestions for the improvement and extension of the investigation.
3–4	A conclusion is **described** which is relevant to the research question and supported by the data presented. A conclusion is described which makes some relevant comparison to the accepted scientific context. Strengths and weaknesses of the investigation, such as limitations of the data and sources of error, are **described** and provide evidence of some awareness of the **methodological issues*** involved in establishing the conclusion. The student has **described** some realistic and relevant suggestions for the improvement and extension of the investigation.
5–6	A detailed conclusion is **described and justified** which is entirely relevant to the research question and fully supported by the data presented. A conclusion is correctly **described and justified** through relevant comparison to the accepted scientific context. Strengths and weaknesses of the investigation, such as limitations of the data and sources of error, are **discussed** and provide evidence of a clear understanding of the **methodological issues*** involved in establishing the conclusion. The student has **discussed** realistic and relevant suggestions for the improvement and extension of the investigation.

Conclusion demonstrates good knowledge of topic. I disagreed with some of the findings but based on preference.

*See exemplars in TSM for clarification.

Communication

This criterion assesses whether the investigation is presented and reported in a way that supports effective communication of the focus, process and outcomes.

0	The student's report does not reach a standard described by the descriptors below.
1–2	**The presentation of the investigation is unclear, making it difficult to understand the focus, process and outcomes.** The report is not well structured and is unclear: the necessary information on focus, process and outcomes is missing or is presented in an incoherent or disorganized way. The understanding of the focus, process and outcomes of the investigation is obscured by the presence of inappropriate or irrelevant information. There are many errors in the use of subject specific terminology and conventions*.

3-4	**The presentation of the investigation is clear. Any errors do not hamper understanding of the focus, process and outcomes.** The report is well structured and clear: the necessary information on focus, process and outcomes is present and presented in a coherent way. The report is relevant and concise thereby facilitating a ready understanding of the focus, process and outcomes of the investigation. The use of subject specific terminology and conventions is appropriate and correct. Any errors do not hamper understanding.

*For example, incorrect/missing labelling of graphs, tables, images; use of units, decimal places. For issues of referencing and citations refer to the "Academic honesty" section.

The paper did not make it clear that only one specific type of alkene oxidation was being considered.

Although the requirements for IA are centred on the investigation, the different types of practical activities that a student may engage in serve other purposes, including:

- illustrating, teaching and reinforcing theoretical concepts
- developing an appreciation of the essential hands-on nature of much scientific work
- developing an appreciation of scientists' use of secondary data from databases
- +developing an appreciation of scientists' use of modelling
- developing an appreciation of the benefits and limitations of scientific methodology.

The practical scheme of work (PSOW) is the practical course planned by the teacher and acts as a summary of all the investigative activities carried out by a student. Students at SL and HL in the same subject may carry out some of the same investigations.

Syllabus coverage

The range of practical work carried out should reflect the breadth and depth of the subject syllabus at each level, but it is not necessary to carry out an investigation for every syllabus topic. However, all students must participate in the group 4 project and the IA investigation.

Planning your practical scheme of work

Teachers are free to formulate their own practical schemes of work by choosing practical activities according to the requirements outlined. Their choices should be based on:

- subjects, levels and options taught
- the needs of their students
- available resources
- teaching styles.