1. a. The reaction shown below is an Aldol-type condensation (more accurately a Claisen-Schmidt condensation). The product exhibits trans stereochemistry in terms of the two phenyl groups.

![Reaction diagram]

b. The best solvent for the reaction would be absolute ethanol. The initial step of the reaction is the formation of the enolate. Since water is formed in this reaction, the presence of water in the system like in 95% ethanol would decrease the amount of enolate, and therefore the rate of the reaction. Dichloromethane would be a very bad choice as well because the hydroxide ion reacts with it as well.

c. Sodium hydroxide is used as base to generate the enolate (see equation).

![Enolate formation equation]

Note that the protons in the methylene protons between the two carbonyl groups are significantly more acidic than the protons on the methyl group ($\text{pK}_a \approx 10$ vs. $\text{pK}_a \approx 20$) because the enolate is better stabilized. As a result, the reaction takes place in the middle and not at the outside.

d. In order to assess the purity of the aldehyde, the experimental refractive index has to be corrected towards the literature conditions (and not the other way around!).

$$n_D^{20} = n_D^x + (X-20)*0.00045 = 1.5440 + (25-20)*0.00045 = 1.5463 \text{ (corr.)}$$

Based on the comparison with the literature value of $n_D^{20} = 1.5460$, he can conclude that the aldehyde is pretty pure since the values hardly differ ($\Delta n_D^{20} < 0.001$).

e. Many aldehydes are contaminated by carboxylic acids because they are relatively easily oxidized in air. The carboxylic acid can be removed by dissolving the aldehyde in diethyl ether, and liquid-liquid extraction with sodium bicarbonate solution, which transfers the acid into the aqueous layer. After drying the organic layer, the solvent is evaporated to leave behind the aldehyde as liquid.

$$\text{HCO}_3^- + \text{RCOOH} \rightarrow \text{RCOO}^- + \text{H}_2\text{O} + \text{CO}_2$$
f. In order to determine the yield, first the limiting reagent has to be determined.

Compound (A): \( n_A = \frac{(2.00 \text{ mL} \times 1.019 \text{ g/mL})}{120.15 \text{ g/mol}} = 17.0 \text{ mmol} \)

Compound (B): \( n_B = \frac{2.00 \text{ g}}{162.19 \text{ g/mol}} = 12.3 \text{ mmol} \)

Product: \( n_P = \frac{3.10 \text{ g}}{264.32 \text{ g/mol}} = 11.7 \text{ mmol} \)

Thus, compound (B) is the limiting reagent in the reaction and 12.3 mmol of product are expected to form.

Yield = \( \frac{n_B}{n_P} \times 100\% = 95\% \)

g. The problem is that phenolic protons are fairly acidic (pKa~10), which means that there is a competition reaction of the phenol function being deprotonated and compound (B) being deprotonated. The deprotonation of the phenol would also deactivate the aldehyde function due to the resonance. In order to avoid this problem, the phenol should be protected by a “TMS”-group.

h. Extra Credit: The subscript “D” in \( n_D^{25} \) stands for the wavelength the refractive index was acquired. In this particular case this is at \( \lambda = 589 \text{ nm} \), which is the yellow line of sodium.
2. a. The oxidation of benzoin is accomplished using bleach (hypochlorite) in a two-phase system (water/ethyl acetate).

\[
\text{O} \quad \text{O} \\
\text{H} \quad \text{O} \\
\text{O} \\
\text{O} \\
\text{C} \quad \text{Cl}^- \\
\text{OCT} \\
\rightarrow \\
\text{O} \\
\text{O} \\
\text{O} \\
\text{O} \\
\text{C}\text{H}_2\text{O} + \text{Cl}^- \\
\]

The reaction affords benzil, water formed from the oxygen atom of the hypochlorite ion and two hydrogen atoms in benzoin, and chloride.

b. The reaction would still work because the crown ether is also able to transport the hypochlorite ion into the organic layer.

\[
\text{O} \\
\text{O} \\
\text{O} \\
\text{O} \\
\text{O} \\
\text{Na} \\
\text{O} \\
\text{Cl} \\
\]

The crown ether complexes the sodium ion, which in turn is able to loosely bind the hypochlorite ion. This ion-complex dissolves fairly well in many organic solvents. Like in the case of tetraalkylammonium salts, the anion is much more reactive now.

c. Since benzoin is used as the limiting reagent, the student should check for its presence. This can be done using chromatographic techniques i.e. gas chromatography or TLC. The easiest method for a Chem 30 BL student is to use TLC. Benzoin is more polar than benzil, and moves less up the TLC plate. If the reaction was completed, the benzoin spot should disappear.

d. The main conclusion that he can draw about the product is that the student probably obtained the correct compound since the color is correct and the melting point is in the correct range. However, the purity is questionable since the melting point is fairly broad (\(\Delta=6^\circ\text{C}\)). In addition, the student’s skills in terms of acquiring the melting point are probably not too great either. Possible sources of error here are: using too much of the sample, heating the sample too fast, poor packing, etc.
3. a. There are various ways to increase the rate of a reaction and which one is most efficient depends on the type of reaction that is carried out. One common approach is the use of a catalyst i.e. concentrated sulfuric acid in the esterification reaction to activate the carbonyl carbon by making it a better electrophile. Another possibility is to increase the temperature in the system by refluxing the mixture, which usually requires a higher boiling solvent.

b. The yield for a reaction with a low equilibrium constant can be improved by taking advantage of the Le Châtelier Principle. In the given case, the yield can only be improved by removing compound B or compound C from the equilibrium. This can be done by precipitating it (proper choice of solvent!), removing it by distillation (as done in the cyclohexene experiment) or by reaction the byproduct further. Since there is only one reactant, it is not possible to apply pressure from the reactant side.

c. The reaction has to be downscaled by a factor fifty. As such the procedure should read like:

“….4 g of compound K and 2 g of compound L are dissolved in 20 mL of ethanol and refluxed for 60 minutes. The reaction mixture is allowed to cool down to room temperature and then placed in an ice-bath. The product is isolated by precipitation using vacuum filtration and washed twice with 2 mL of ice-cold ethanol…..”

Note that the amounts of reactants and solvent are downscaled but not the time since this is a question of kinetics, which does not change much with the total amount of material being used.
4. a. The best way of improving the run is by using a temperature gradient starting with the same temperature \(T=80\,^\circ\text{C}\) and increasing the temperature to maybe \(T=150-200\,^\circ\text{C}\) within 10-20 minutes. This would still afford a good separation for the compounds but also decrease the retention times for the later compounds and make those peaks sharper as well. A significantly higher temperature alone would probably cause problems in the separation of compounds that elute early on, particularly if they are already relatively close together.

b. Most stationary phases used in gas chromatography are actually high boiling liquids (often polymers) that coat some solid support material, and not solids. The operation temperature has to be significantly below the boiling point of these compounds to avoid column bleeding. In addition, some stationary phases are temperature sensitive i.e. cyclodextrin column, and the temperature has to be below the decomposition temperature of these compounds.

c. The retention time depends on a lot of parameters such as temperature, pressure, flow rate, column length and condition, loading, etc. Since it is very difficult to reproduce all these parameters exactly, retention times are hardly reported in the literature.

d. In order to assess the composition of the mixture, the peak area and the response factors have to be known. In case of the isoborneol experiment, the assumption was made that the response factors are the same for borneol and isoborneol. However, they have to be experimentally determined, because they vary based on the compound and the detector system used. Taking the response factors into account, the peak areas can be corrected accordingly before getting the relative composition.

e. Extra Credit: The abbreviation “FID” stands for “flame ionization detector”.

5. a.

The stationary phase is polar, while the solvent (dichloromethane) is weakly polar. The first lane shows compound A only, which exhibits a fairly low \( R_f \)-value due to its high polarity. Compound B, which is medium polar, has a higher \( R_f \)-value than compound A. The third lane shows four spots. Since the reaction is incomplete, spots for compound A and compound B appear in the appropriate heights. In addition, spots for compound C and compound R appear further up the plate. The spot the furthest up the TLC plate is due to compound C since this compound is non-polar and has very little chance to interact with the stationary phase.

b.

Since the reaction has a fairly high equilibrium constant \( (K_{eq}=10^6) \), it virtually goes to completion. Based on the data given in the problem, compound A is the limiting reagent, which means that the sport does not show up in the third lane anymore. All spots exhibit lower \( R_f \)-values because the polarity and therefore the eluting power of the solvent decreased due to the addition of hexane.

c. Dichloromethane is used as solvent because it dissolves a broad variety of compounds, has a low polarity and a low boiling point. The latter two properties ensure that the solvent does not interfere with the separation process by causing the formation of crescent shaped spots.
6. a. The difference of boiling point is a result of the different strength of intermolecular forces. For both compounds, dipole-dipole interactions are the dominating intermolecular force. Compound E has a larger dipole moment because there is a strongly electron-donating group on one side of the ring, and an acceptor group on the other side of the ring. As a result, compound E has a higher boiling point than compound D. In addition, there is a slight increase in mass (by 16 mass units), but this cannot account for an increase boiling point of 30+ °C.

b. Compound F would have the lower Rf-value here because ketones are generally more polar than aldehydes. The can form an enol more readily, which allows for hydrogen bonds to form to the stationary phase. Another way to look at it is that the bipolar resonance form is better stabilized if two R-groups are attached to the carbonyl group.

c. Diethyl ether is weakly polar and therefore is able to dissolve a broad variety of compounds. In addition, it forms the second layer with water because it possesses a limited miscibility. Finally, it has a low boiling point, which allows for easy removal later on. However, one of the disadvantages is its high flammability.

d. The spectrum looks very different if it was acquired in liquid or in the gas phase. This holds particularly true for polar compounds like alcohols. In the liquid phase cyclohexanol exhibits strong intermolecular hydrogen bonding which results in a broad peak in the 3200-3600 cm\(^{-1}\) range. In the gas phase, these hydrogen bonds are not observed, which means that the peak is much sharper and also shifted to higher wavenumbers.

e. Sodium sulfate is generally used as drying agent to remove water and other very polar compounds. The drying process is favored at low temperatures, but reverses at higher temperatures (large entropy increase!), which makes it necessary to remove the drying agent prior removal of the solvent or distillation.

\[
Na_2SO_4 + 10 H_2O \leftrightarrow Na_2SO_4 \cdot 10 H_2O
\]

f. In order to obtain an infrared spectrum for viscous oils, the student cannot use the common techniques like KBr pellets or AgCl plates directly, because neither one produces good results due to the difficulties to control the amount of sample placed in the infrared beam and the sample preparation itself. The best way would be to dissolve some of the sample in a small amount of a low boiling solvent like dichloromethane. A few drops of the solution are then applied to the AgCl plates. The solvent is then evaporated, which leaves behind a thin film of the oil on the AgCl plate. If the signals are too small, more of the solution can be applied.
g. The lubrication of the joints has two functions. First, it allows for a better seal between the joints, which is important to get a good vacuum. Secondly, it makes it easier to disconnect the joints later on as well since the joints do not freeze up as often.

h. This is a very poor choice because the NMR spectrometer requires a deuterium signal in order to lock the magnetic field. In addition, the chloroform would show as a strong signal (singlet at $\delta=7.26$ ppm) in the $^1$H-NMR spectrum as well which makes it even more difficult to observe any signals.
7. a. Compound V dissolves fairly poorly in isopropanol, a fairly polar solvent. On the other hand side, it dissolves very well in a weakly to medium polar solvent like ethyl acetate, which means that it has to have a similar polarity. As a result, the polarity of the compound should be around 2.5-3 on the polarity scale.

b. The most suitable solvent for recrystallization is cyclohexane because the solubility increases the most in this solvent over the given temperature range. The solubility only doubles in case of ethyl acetate, and triples for isopropanol, while it increases by a factor eight in cyclohexane. In addition, the impurity is weakly polar, which means that it should dissolve fairly well in cyclohexane as well.

c. The student would require 12 mL of ethyl acetate (=4.8 g/(40 g/100 mL)) to dissolve the sample at 80 °C. At 0 °C, 2.4 g (=12 mL * 20 g/100 mL) of the sample remain in solution and 2.4 g (=4.8 g - 2.4 g) of the compound precipitate. Overall, this solvent is a very poor choice for recrystallization since half of the sample is lost in the process.

d. Slow crystal growth is important due to various reasons. First, the slow growth allows for purer crystals to form since less impurities are being trapped. Secondly, the crystals are bigger and therefore have less surface area, which means that it is easier to remove the impurities on the surface more efficiently.
8. **Spectrum 1: Compound G**

Characteristic peaks in cm\(^{-1}\): 2300-3400 (OH, broad, acid), 1680 (C=O, conj. acid), 1613, 1515 (C=C, aromatic), 1420 (CH\(_3\), bend), 1287 (C-O, acid), 757 (oop, para-subst.)

**Spectrum 2: Compound F**

Characteristic peaks in cm\(^{-1}\): 3000-3050 (CH, sp\(^2\)), 2864-2964 (CH, sp\(^3\)), 2733, 2829 (CHO, aldehyde), 1702 (C=O, aldehyde), 1485, 1585 (C=C, aromatic), 1450 (CH\(_3\), bend), 1040, 790 (C-O, ether)

**Spectrum 3: Compound A**

Characteristic peaks in cm\(^{-1}\): 3113-3026 (CH, sp\(^2\)), 2859-2976 (CH, sp\(^3\)), 1614, 1517 (C=C, aromatic), 1517, 1343 (NO\(_2\)), 1449, 1382 (CH\(_3\), bend)

**Spectrum 4: Compound L**

Characteristic peaks in cm\(^{-1}\): 3008-3072 (CH, sp\(^2\)), 2887-2956 (CH, sp\(^3\)), 1656 (C=C, alkene), 1448 (CH\(_2\), bend), 708 (oop, cis-alkene)

**Spectrum 5: Compound D**

Characteristic peaks in cm\(^{-1}\): 3330 (OH, alcohol), 2870-2955 (CH, sp\(^3\)), 1457, 1378 (CH\(_2\), bend), 1006 (C-OH)

**Spectrum 6: Compound K**

Characteristic peaks in cm\(^{-1}\): 3314 (CH, sp), 2872-2961 (CH, sp\(^3\)), 2121 (C=C, alkyne), 1470, 1388 (CH\(_2\), CH\(_3\), bend), 629 (CH, sp, bending)

**Spectrum 7: Compound C**

Characteristic peaks in cm\(^{-1}\): 3437 (NH, sec. amine), 3014-3050 (CH, sp\(^2\)), 2889-2972 (CH, sp\(^3\)), 1608, 1517 (C=C, aromatic), 1446, 1378 (CH\(_3\), bend), 748 (oop, ortho-subst.)

**Spectrum 8: Compound J**

Characteristic peaks in cm\(^{-1}\): 3034-3068 (CH, sp\(^2\)), 2934 (CH, sp\(^3\)), 1694 (C=O, conj. ester), 1594, 1493 (C=C, aromatic), 1433, 1371 (CH\(_3\), bend), 1194, 1027 (C-O, ester), 749, 692 (oop, mono-subst.)
9. a. The compound has 5 degrees of unsaturation (=\((11*2+2-15+1)/2\)).

b. Pertinent peaks are at 3020 cm\(^{-1}\) (CH(sp\(^2\))), 2820-2977 cm\(^{-1}\) (CH(sp\(^3\))), 1696 cm\(^{-1}\) (C=O, conj. ester), 1608, 1528 cm\(^{-1}\) (C=C, aromatic), 1445, 1366 (CH\(_2\), CH\(_3\), bend), 1188, 1020 cm\(^{-1}\) (C-O), 788 (oop, para-subst.)

c. There are eight peaks for 11 carbons total, which indicates some symmetry, most likely in the benzene ring.

d. The \(^1\)H-NMR shows two doublets at \(\delta=6.63\) (d, 2H) and \(\delta=7.91\) (d, 2H) ppm, which are indicative of a para-disubstituted benzene ring. The quartet at \(\delta=4.31\) ppm (q, 2H) is a methylene group next to a methyl group and an oxygen atom. The singlet at \(\delta=3.02\) ppm (s, 6H) is due to two methyl groups attached to a nitrogen atom. The triplet at \(\delta=1.36\) ppm (t, 3H) is a result of a methyl group attached to a methylene function.

e. The \(^{13}\)C-NMR spectrum shows three quaternary carbon atoms (117, 153 and 167 ppm (C=O)), two CH functions (131 and 111 ppm), one CH\(_2\) function (60 ppm) and two CH\(_3\)-functions (40 and 14 ppm).

f. The compound is ethyl- p-(dimethylamino)benzoate.