1. a. The first reaction is a reduction of a carboxylic acid using lithium aluminum hydride leading to a benzylic alcohol, and not an aldehyde. The second reaction is a substitution reaction that affords a benzylic bromide. In the first part of reaction 3, a Grignard reagent is generated in-situ that is reacted with benzaldehyde to yield a chiral secondary alcohol.

![Diagram of reactions]

b. A good solvent for a reaction should be able to dissolve the reactants but not react with them or interfere otherwise with the reaction. Since the carboxylic acid and lithium aluminum hydride are fairly polar, a polar solvent has to be used here. Recall that reductions with lithium aluminum hydride (LAH) are frequently carried out in THF, which would work in this case as well. Alternatively, diethyl ether or 1,2-dimethoxyethane can be used as well. Alcohols cannot be used here because they will react with LiAlH₄ immediately!!

c. In order to reduce 0.04 mol of compound A, 0.03 mol of LiAlH₄ is required. One hydride used in the reaction with the acidic proton and two more hydrides are needed to reduce the carboxylate to the alcohol. This means that three molecules LiAlH₄ can reduce four molecules of compound A.

d. If NaBH₄ was used instead of LiAlH₄, the carboxylic acid group would not be reduced. Sodium borohydride is a weaker reducing reagent and only reacts with ketones and aldehydes (see lecture). In the reaction, the carboxylic acid group would be temporarily deprotonated due to the reaction of the hydride with the acidic proton of the carboxylic acid (leading to hydrogen gas), but after the acidic work-up be reprotonated.

\[
\text{RCOOH} + \text{"H"} \rightarrow \text{RCOO}^- + \text{H}_2
\]

e. In order to determine the yield, the limiting reagent has to be identified first.

\[n_A = 0.75 \text{ g}/152.15 \text{ g/mol} = 0.0049 \text{ mol}\]

\[n_{\text{LAH}} = 0.40 \text{ g}/37.95 \text{ g/mol} = 0.0105 \text{ mol}\]

In order to reduce 0.0049 mol of compound A, 0.0037 mol of LiAlH₄ are required (see c.). Since about three times as much LAH is present, the carboxylic acid is clearly the limiting reagent here. Thus, 0.0049 mol of the benzylic alcohol should be formed.

\[n_B = 0.55 \text{ g}/138.16 \text{ g/mol} = 0.0040 \text{ mol}\]
Thus, the yield of the reaction is \(81\%\) (=0.0040 mol/0.0049 mol * 100%).

f. Reaction 3 is a Grignard reaction. Thus, ethers like diethyl ether or tetrahydrofuran should be used because these solvent usually do not react with the Grignard reagent. Diethyl ether is preferential here since it allows for an easier isolation of the product because of its phase separation with the aqueous layer.

g. The phenol group on the reactant poses a big problem because it would react with the Grignard reagent in an acid-base reaction. The experimenter either has to add two equivalents of the Grignard reagent (which is a waste) or has to protect the phenolic hydroxyl function with a TMS-group, which converts it into a trimethylsilyl ether, which is inert towards the Grignard reagent.

h. Extra credit: Reaction 3 affords to enantiomers of the secondary alcohol in a 50:50-ratio because neither approach of the Grignard reagent is favored in this case.
2. a. The reaction presented here is a crossed aldol condensation. Compound E, acetophenone, can also react with itself if no other electrophiles are present. An excess of compound F can prevent or minimize this side reaction.

b. Compound X should be a base like potassium hydroxide. This compound acts as a catalyst and helps to produce the enolate ion from compound E, which acts as a nucleophile in the reaction.

c. The best solvent for the reaction would probably be absolute ethanol like in the lab. However, methanol should work as well because acetophenone is a liquid at room temperature and benzophenone dissolves reasonably well in methanol at higher temperatures. Dichloromethane and ethyl acetate are very poor choices because they would both react with the base catalyst, either by being deprotonated or by hydrolysis.

d. Based on the literature, compound G would exhibit the lowest C=O stretching frequency (E: 1685 cm\(^{-1}\), F: 1660 cm\(^{-1}\), G: 1645 cm\(^{-1}\)). The low frequency can be explained by the extended conjugation found in compound G.

e. In order to access the purity of the compound, the observed refractive index has to be corrected for the temperature difference first.

\[
\Delta n_D^{15} = n_D^{20} - (15-20) \times 0.00045 = 1.5300 + 5 \times 0.00045 = 1.5323 \text{ (corr.)}
\]

The comparison with the literature value of \(n_D^{15} = 1.5314\) shows that compound E is reasonably clean because the observed refractive index is within \(\Delta n = 0.001\) of the literature value.

f. Compound E exhibits a boiling point of \(T_b = 100^\circ\text{C}\) at \(p = 25\text{ mmHg}\) (±5 mmHg).
g. The fact that compound \( G \) has a lower melting point and a broader melting point range that stated in the literature allows the conclusion that the compound is not entirely pure. Impurities generally cause a melting point depression and a broader melting point since the entire sample does not melt at the same time. The nature of the impurity cannot be determined without any further tests i.e. TLC. The compound is either contaminated with the reactants, intermediates or is plain not completely dry.
3.a. Compound P has the lowest boiling of these four compounds (b.p.=197 °C). The reason is that this compound has the lowest dipole moment of these compounds. In addition, the hydroxyl group is not very active in terms of intermolecular hydrogen bonds since it forms a very strong intramolecular hydrogen bond. Due to the ability to form intermolecular hydrogen bonds, compound N and compound O have very high boiling points (above 300 °C). Compound Q exhibits a large dipole moment due to the special charge separation induced by the donor and acceptor attached to the benzene ring (b.p.=250 °C).

b. Compound N exhibits the highest melting point of these compounds (N: 117 °C, O: 72 °C, P: -7 °C, Q: 0 °C). This can be explained by the large dipole moment in the molecule induced by the para-substitution of the ring with a donor and an acceptor group. In addition, the ability to form strong intermolecular hydrogen bonds and the high symmetry (Carnelley Rule) increase the melting point as well (i.e. the meta isomer melts at 106 °C).

c. Compound P has the highest solubility in benzene. Benzene is a non-polar solvent which dissolves non-polar compounds better than polar compounds. Based on the discussion above, compound P is the least polar compound of these four compounds. The solubility of compound P is 75.7 g/100 mL (12 °C), while compound N only dissolves 3.8 g/100 mL (65 °C), which means that the solubility at room temperature will be much lower.

d. Compound Q would exhibit the highest Rf-value at a polar stationary phase because it is the only compound that cannot for hydrogen bonds with the Si-O functions of the silica. The other compounds can form these hydrogen bonds because they possess either OH or NH functions.
4. a.

The stationary phase is polar ($\text{SiO}_2$) and the mobile phase is weakly polar. Thus, the weakly polar compound $R$ exhibits the highest $R_f$-value and the polar product $T$ the lowest $R_f$-value. Since the reaction is incomplete at this point, both reactants appear in the third lane as well.

b.

The stationary phase is still polar, but the mobile phase is less polar than before (more non-polar solvent). Thus, all spots will travel less up the plate resulting in lower $R_f$-values for all three compounds. The spots for the reactants disappeared in the product lane because both of them are completely consumed because of molar ratio chosen and large equilibrium constant of the reaction.

c. The compounds $S$ and $T$ are spotted as internal references. The problem with TLC is that very few $R_f$-values are reported in the literature because too many parameters impact them i.e. solvent variations, activity of the stationary phase, temperature, amount of material spotted, etc.
5. a. The Diels-Alder reaction uses anthranilic acid and isopentynitrite to produce benzylene \textit{in-situ}, which is immediately reacted with tetraphenylcyclopentadienone to form isopentyl alcohol, tetraphenynaphthalene, nitrogen, carbon monoxide and carbon dioxide gas.

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\begin{align*}
\text{Anthranilic Acid} + \text{Isopentynitrite} &\rightarrow \text{Benzyne (in-situ)} \\
&\rightarrow \text{Isopentyl Alcohol} + \text{Tetraphenynaphthalene} + \text{Nitrogen} + \text{Carbon Monoxide} + \text{Carbon Dioxide Gas}
\end{align*}
```

b. Diethyl ether would not be a good solvent for this reaction. The solubility of the anthranilic acid would be fairly low because the anthranilic acid is very polar. Secondly, the temperature in the reaction would be much lower as well which would slow down the reaction in various ways. The reaction is entropy driven which implies that higher temperatures are favorable here. This applies in particular to the last step, in which CO is eliminated from the Diels-Alder adduct.

c. The expected observations are a color change of the solution from dark purple (TPCP) to yellow-orange upon the consumption of the TPCP. In addition, the mixture is foaming a lot due to the formation of three moles of gases (nitrogen, carbon monoxide and carbon dioxide).

d. It usually takes a lot of time to dissolve the crude product in the isopropanol, and subsequently for the pure product to precipitate as well. These difficulties often have to do with a wetting problem of the crystals. The product is fairly non-polar and therefore the isopropanol has only one orientation that favors the dissolution process (non-polar end towards the TPN molecule).

e. The final product is fairly symmetric and also has a low polarity overall (only carbon and hydrogen atoms). A lot of the expected vibrational modes are not IR active, because the dipole moment does not change, or if they are IR active, the dipole moment changes very little resulting in low intensity peaks.
6. a. There are several reasons why drying agent should be used sparingly. First, they cost money and produce waste after they were used. Secondly, the drying agent can also absorb the target compound, which is particularly a problem if the compound is very polar i.e. alcohols, etc. Excessive amounts of drying agent can also cause separation problems in liquid-solid systems. The proper protocol starts with small amounts and asks to add more if necessary after some time. If the solution is dry, some of the drying agent is floating around upon swirling. The solution is usually translucent then as well.

b. The extraction with saturated sodium bicarbonate solution serves to remove the sulfuric acid dissolved in the organic layer. If this step was skipped during the work-up, the student would observe a lot of elimination/rearrangement product in his final product.

\[
H^+ + HCO_3^- \rightarrow \text{“H}_2\text{CO}_3” \rightarrow H_2O + CO_2
\]

As long as acid is being neutralized, the formation of carbon dioxide in the form of bubbles and/or an overpressure in the extraction container will be observed. Thus, the separatory funnel should be vented frequently to avoid a pressure build-up.

c. The stretching mode of an hydroxyl function (\(\nu(O-H)\)) is more intense than a stretching mode of an amine function (\(\nu(N-H)\)) because the OH group is more polar. The higher polarity also results in stronger intermolecular and intramolecular hydrogen bonds, which causes a peak broadening.

d. Tetraphenylcyclopentadienone has various functional groups that can absorb UV-vis radiation namely C=C and C=O bonds. The absorptions that are due to the alkene function and the benzene rings are below \(\lambda=300\) nm. Thus, the peaks at \(\lambda=330\) nm and \(\lambda=500\) nm are due to the carbonyl function in the molecule. The peak at \(\lambda=330\) nm is due to the \(\pi-\pi^*\)-transition while the peak at \(\lambda=500\) nm is a result of the \(n-\pi^*\)-transition. The assignment is based on the fact that the energy gap of the \(n-\pi^*\)-transition is smaller than the one for the \(\pi-\pi^*\)-transition, which results in an absorption at higher wavelength \((\Delta E=hc/\lambda)\). The peaks will shift if a different solvent is used because the interaction of the solvent changes the orbital energies slightly. In this case, the \(\pi-\pi^*\)-transition will experience a hypsochromic shift while the \(n-\pi^*\)-transition will show a bathochromic shift.

e. All extractions are carried out at room temperature in Chem 30BL. The compound has to exhibit a high solubility in the solvent at room temperature in order to be a good solvent for extraction. However, for recrystallization the solubility at room temperature should be fairly low in order to recover a significant amount of the product in this procedure. Since a solvent cannot fulfill both requirements, it can only be used for either technique.

f. The problem here is that despite the different polarities of benzil and benzoin, the two compounds virtually have the same boiling point, which determines their vapor pressure. Thus, a simple argument using different boiling points will not work here. In order to identify the compounds, the samples have to be spiked (addition of either compound) or the authentic compounds have to be run under the same conditions. It turns out that it is
fairly difficult to separate these compounds in the GC (which is done in the Chem 174 course).

g. The solution superheated which ultimately lead to bumping or heavy foaming. The solvent spilled out and got in contact with the hot hotplate which caused it to ignite. The student should have added a boiling stick, boiling stones or spin bar to agitate the solution which allows for a smoother boiling. In addition, the hot plate setting has to be lower as well.

h. Extra credit: The *Carnelley Rule* basically states that isomers with higher symmetry have higher melting points compared to less symmetric isomers. For instance, among the dichlorobenzenes the para isomer has the highest melting point despite having a net dipole moment of zero (ortho: m.p. = -16.7 °C, meta: m.p. = -26.3 °C, para: m.p. = 54 °C)
7.a. Compound \( \text{V} \) dissolves fairly poorly in non-polar solvents like petroleum ethers. The solubility increases significantly in propanol over the given temperature range which means that the compound has to have a certain polarity. The absolute solubility is the highest in ethyl acetate. Thus, the compound is medium polar (3±0.5 on polarity scale).

b. The most suitable solvent for recrystallization is propanol here because the compound shows the steepest solubility curve in this solvent (solubility increase of factor 7.5). In addition, the impurity is more polar than compound \( \text{V} \), which means that it should dissolve better than compound \( \text{V} \) in this solvent.

c. Based on the data given in the table, the student requires 20 mL (=3.0 g/(15 g/100 mL)) of propanol to dissolve the compound at 100 °C. Upon cooling to 0 °C, 0.4 g (=20 mL * (2 g/100 mL)) of the compound remain in solution and 2.6 g (=3.0 g- 0.4 g) are recovered as solid.

d. A slow crystallization usually leads to better shaped crystals (flat surfaces, shiny) that possess less surface area. Fewer impurities get trapped as well during a slow crystallization process, which is the entire purpose of this step.
8. **Spectrum 1: Compound C**

Characteristic peaks at cm\(^{-1}\): 3029-3068 (CH\(_{sp}^3\)), 2926-2963 (CH\(_{sp}^3\)), 2733, 2856 (CHO, aldehyde), 1697 (C=O, conj. aldehyde), 1487, 1601 (C=C, aromatic), 1381, 1458 (CH\(_3\), bend), 754 (oop, ortho subst.)

**Spectrum 2: Compound J**

Characteristic peaks at cm\(^{-1}\): 3366 (OH, alcohol), 2876-2961 (CH\(_{sp}^3\)), 1378, 1460 (CH\(_2\), CH\(_3\), bend)

**Spectrum 3: Compound H**

Characteristic peaks at cm\(^{-1}\): 2879-2973 (CH\(_{sp}^3\)), 1713 (C=O, ketone), 1378, 1455 (CH\(_2\), CH\(_3\), bend)

**Spectrum 4: Compound K**

Characteristic peaks at cm\(^{-1}\): 2500-3500 (OH, carboxylic acid), 1691 (C=O, conj. acid), 1360, 1492, 1578 (C=C, aromatic), 1383, 1455 (CH\(_3\), bend), 759 (oop, ortho subst.)

**Spectrum 5: Compound E**

Characteristic peaks at cm\(^{-1}\): 3270, 3373 (NH\(_2\), prim. amine), 3027, 3086 (CH\(_{sp}^3\)), 2858-2920 (CH\(_{sp}^3\)), 1496, 1605 (C=C, aromatic), 1453 (CH\(_2\), bend), 698, 739 (oop, mono-subst. arene)

**Spectrum 6: Compound G**

Characteristic peaks at cm\(^{-1}\): 3063-3113 (CH\(_{sp}^3\)), 2873-2967 (CH\(_{sp}^3\)), 1513, 1606 (C=C, aromatic), 1347, 1513 (NO\(_2\)), 1366, 1464 (CH\(_3\), bend)

**Spectrum 7: Compound I**

Characteristic peaks at cm\(^{-1}\): 3001-3081(CH\(_{sp}^3\)), 2853, 2974 (CH\(_{sp}^3\)), 1639 (C=C, alkene), 1450 (C=C, aromatic), 910, 992 (oop, monosubst. alkene)

**Spectrum 8: Compound B**

Characteristic peaks at cm\(^{-1}\): 3298 (NH, sec. amide), 3031-3064 (CH, sp\(^3\)), 2828-2924 (CH, sp\(^3\)), 1646 (C=O, amide), 1499, 1586 (C=C, aromatic), 1376, 1453 (CH\(_2\), CH\(_3\), bend), 695, 750 (oop, monosubst. arene)
9. a. Degree of unsaturation: \[ \text{D.U.} = \frac{(2\times C + 2 - H + N)}{2} = \frac{(2\times 10 + 2 - 18)}{2} = 2 \]

b. The most important peaks are at (in cm\(^{-1}\)): 2878-2980 (CH, sp\(^3\)), 1736 (C=O, ester), 1370, 1448 (CH\(_2\), CH\(_3\), bend), 1036, 1205 (COC, ester)

c. The \(^1\)H-NMR spectrum shows five signals. The quartet at 4.19 ppm (4H) is due to two methylene functions next to methyl groups and an oxygen atom. The doublet at 3.10 ppm (1H) is due to a CH function next to another CH function and some electron-withdrawing groups. The next signal, a multiplet at 2.41 ppm (1H) is due to a CH function that is attached to CH functions with many hydrogen atoms (i.e. methyl groups). The triplet at 1.27 ppm (6H) is a result of two methyl groups next to methylene functions (\(--\rightarrow\) ethyl group). Finally, the doublet at 1.00 ppm (6H) is due to two methyl groups next to a CH function (\(--\rightarrow\) isopropyl group).

d. The \(^{13}\)C-NMR spectrum exhibits six signals, which means that the molecule is fairly symmetric. The signal at 169 ppm is due to quaternary carbon atom (carbonyl function of ester). The signals at 29 and 57 ppm are due to CH functions. The signal at 61 ppm is a result of a methylene function, while the signals at 14 and 20 ppm are due to two different methyl groups.

e. Based on the discussion above, compound W is **diethyl isopropylmalonate**.