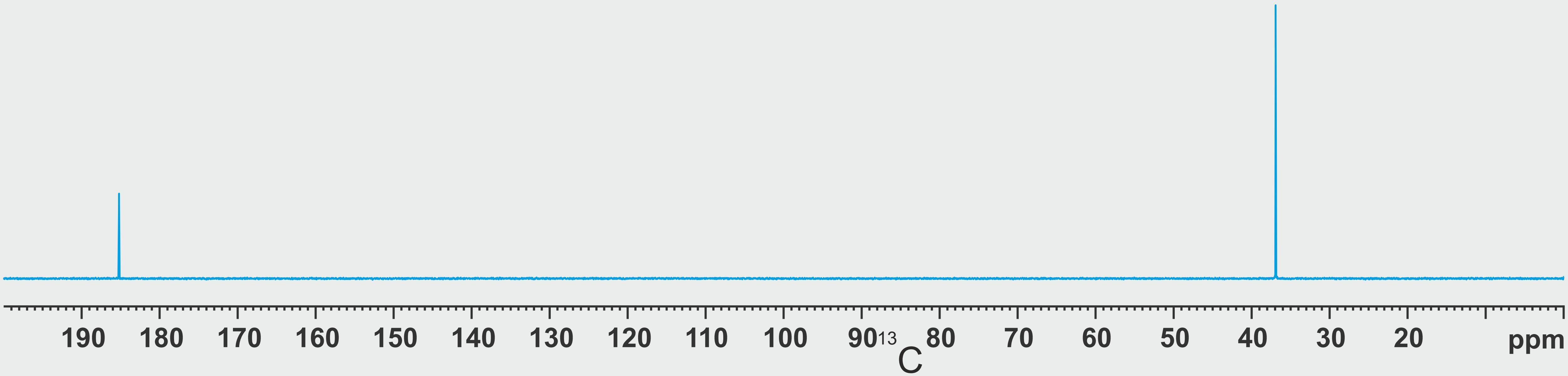
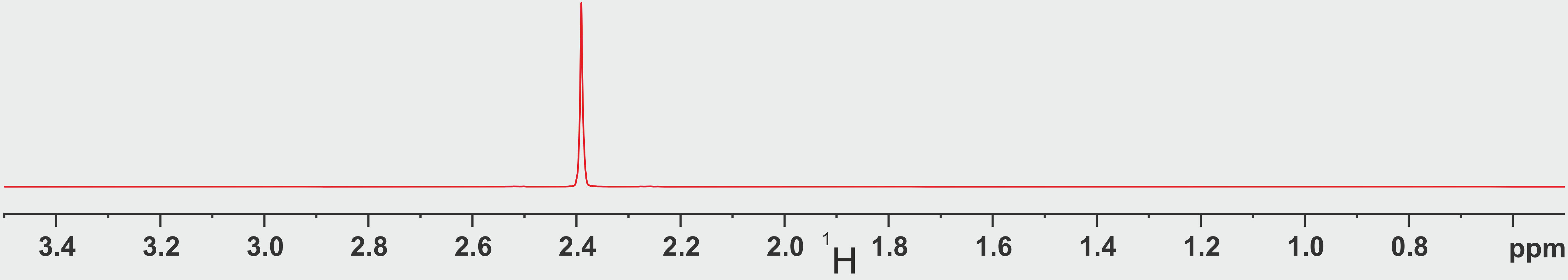
Exercise plus Solution – Quick overview

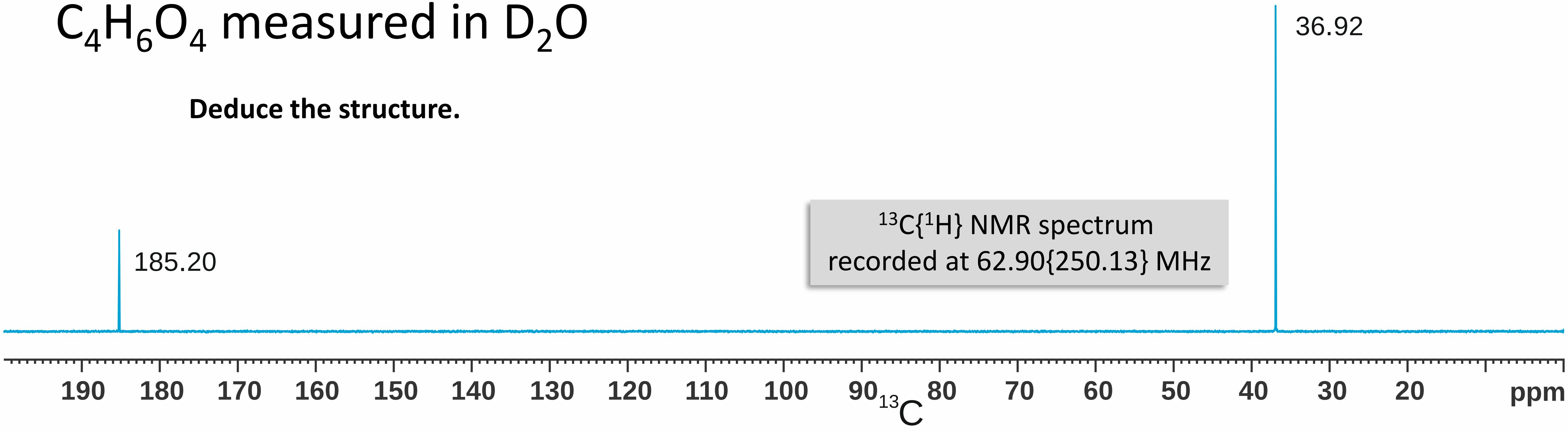
It is recommended to use this version only for a quick overview of the NMR challenge. All animations of the PowerPoint version are missing, under certain circumstances quality deficiencies may also occur.
The higher quality PowerPoint files are freely available for download at any time.



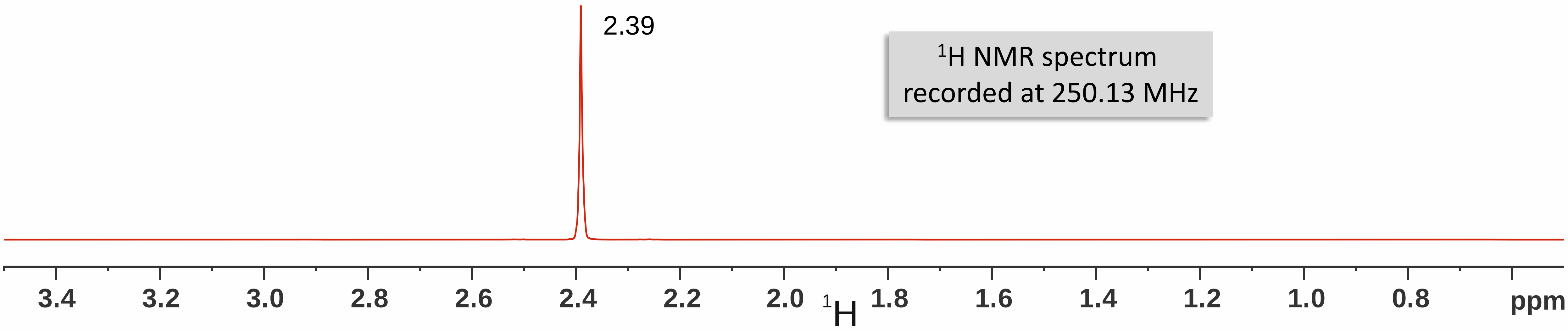


$C_4H_6O_4$ measured in D_2O

Deduce the structure.



$^{13}C\{^1H\}$ NMR spectrum recorded at 62.90{250.13} MHz



^1H NMR spectrum recorded at 250.13 MHz

Solution

$C_4H_6O_4$

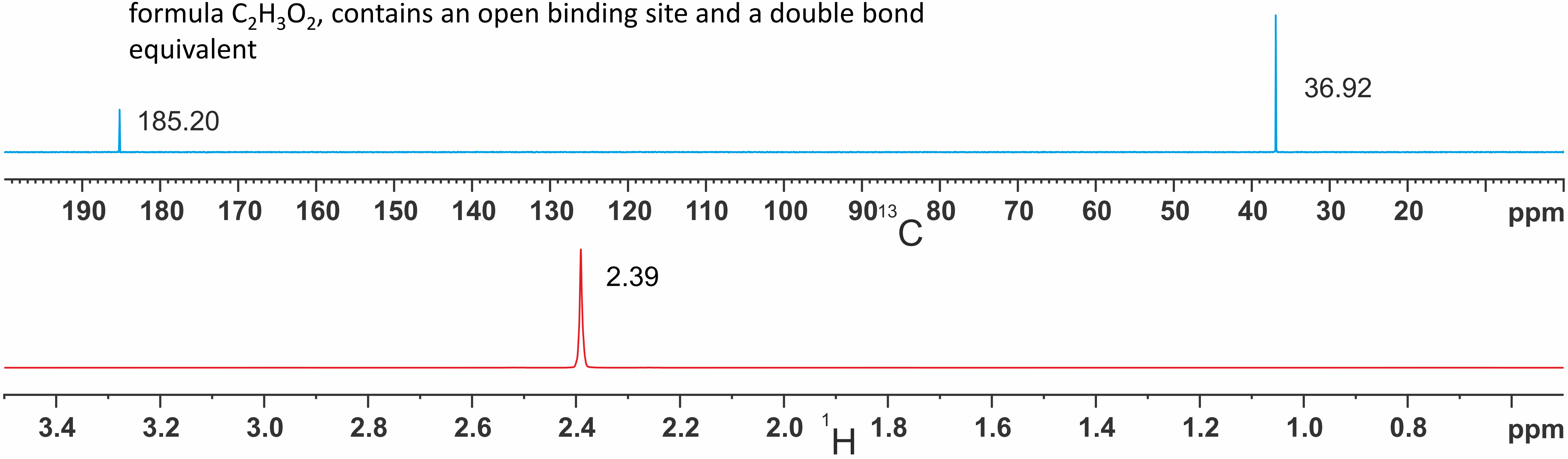
$$n_{\mathrm{DBÄ}} = \frac{2n_{\mathrm{C}} - n_{\mathrm{H}} + 2}{2}$$

First results:

- two double bond equivalents
- **four** carbon atoms, but **only two carbon signals** in the NMR spectrum
- **six** protons, but **one singlet only**

Probable explanation:

- a symmetrical molecule **R – R**, where **– R** corresponds to the molecular formula $C_2H_3O_2$, contains an open binding site and a double bond equivalent



wanted: -$C_2H_3O_2$ with 1 DBE

H : 2.39 ppm

C : 36.92 ppm

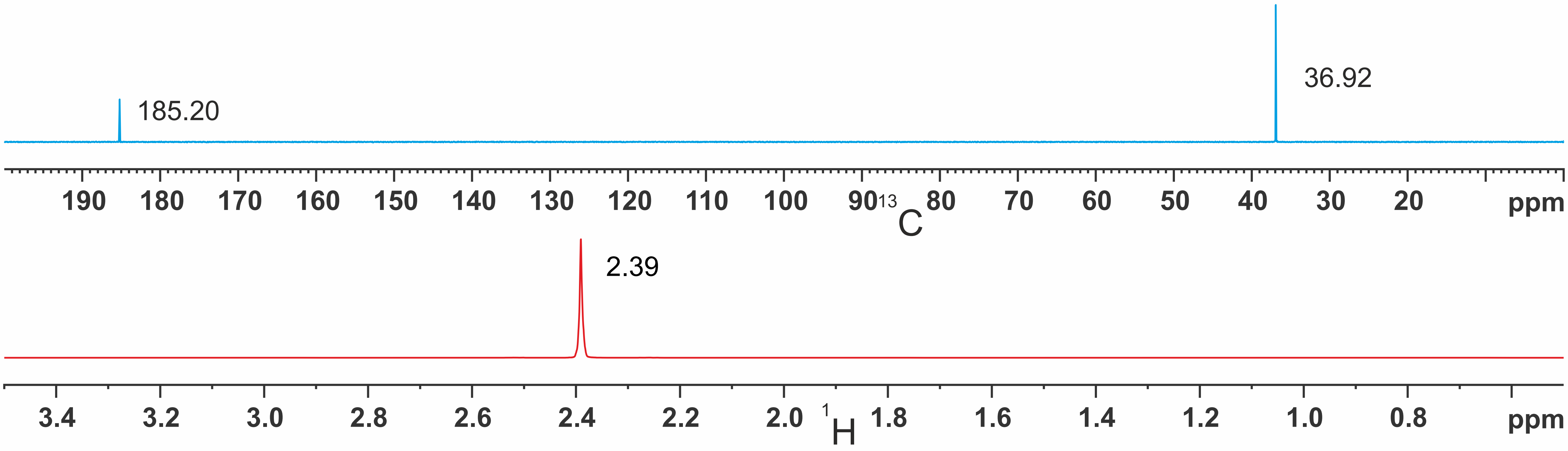
C : 185.20 ppm

Solution

Let's write down the half-molecule fragment we are looking for and the little known information on sticky notes.

$C_4H_6O_4$

$$n_{\mathrm{DBE}} = \frac{2n_{\mathrm{C}} - n_{\mathrm{H}} + 2}{2}$$



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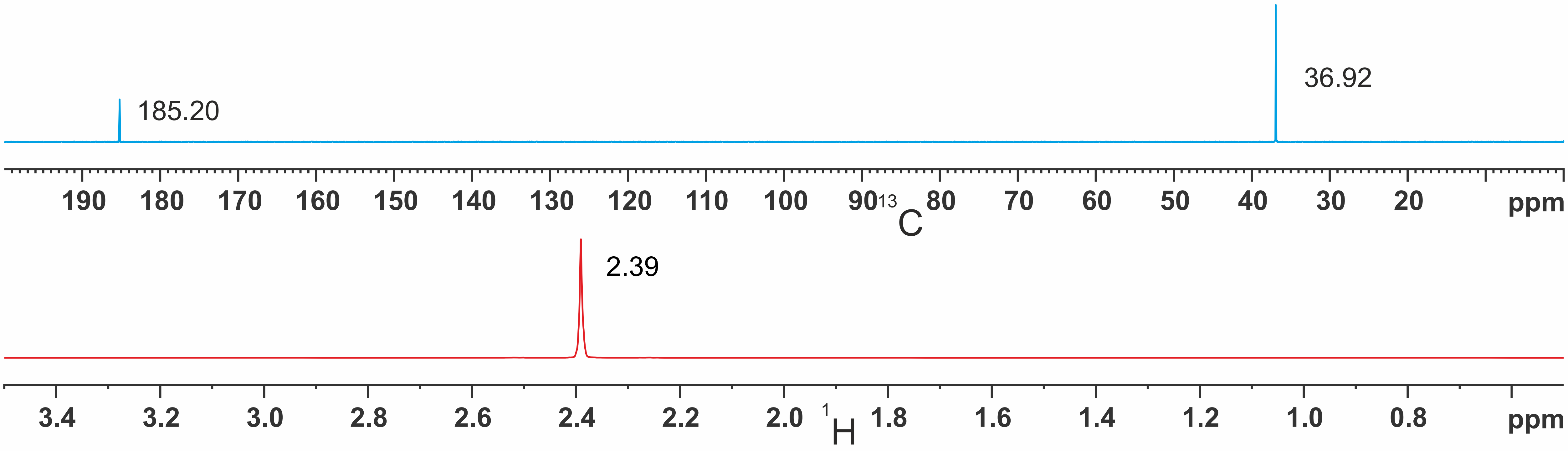
Solution

Let's write down the half-molecule fragment we are looking for and the little known information on sticky notes.

We no longer need the information-poor spectra.

$C_4H_6O_4$

$$n_{\mathrm{DBE}} = \frac{2n_{\mathrm{C}} - n_{\mathrm{H}} + 2}{2}$$



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Let's write down the half-molecule fragment we are looking for and the little known information on sticky notes.

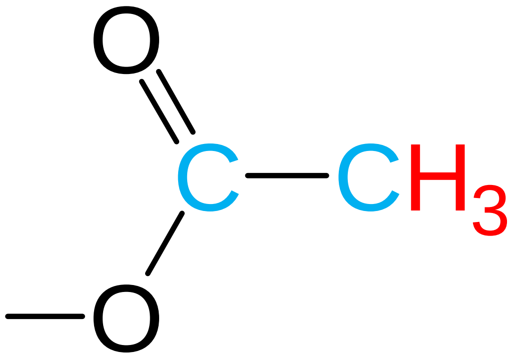
We no longer need the information-poor spectra.

Our first view is the carbon signal at 185.20 ppm.

This is, of course, a carbonyl group.

A small interim calculation:

- wanted: **$-C_2H_3O_2$ + 1 DBE**
- found: **-CO- + 1 DBE**
- missing: **CH_3O** without **DBE**



At first glance, this looks like either a methoxy group or a single oxygen atom plus a methyl group. Let's try the second version. A look at the overview tables of the chemical shifts let us expect the measured values in the carbon as well as in the proton range.

But ...

wanted: -$C_2H_3O_2$ with 1 DBE

H : 2.39 ppm

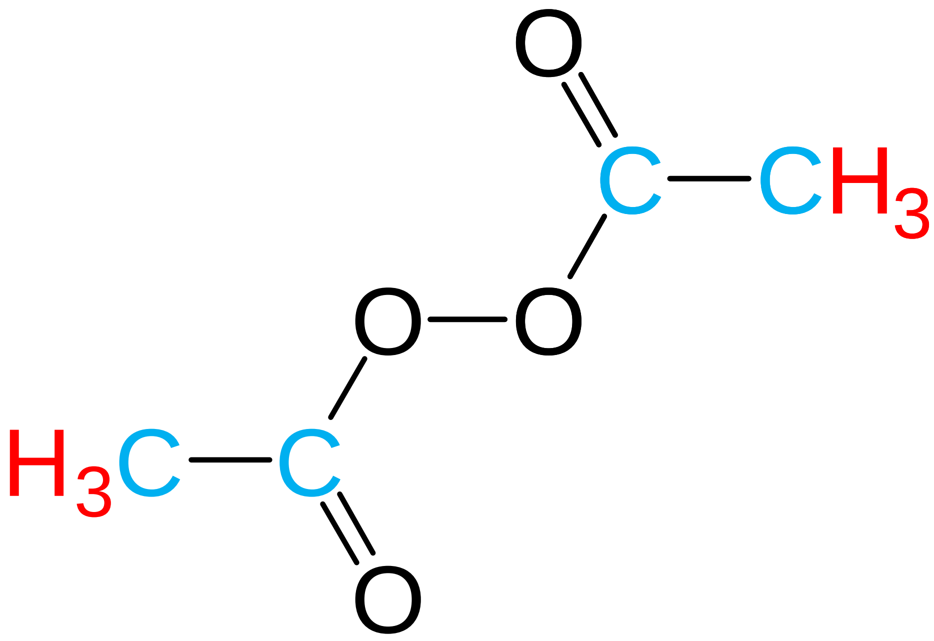
C : 36.92 ppm

C : 185.20 ppm

... that was only half the molecule and after adding the mirror-imaged second half of the molecule, you get a richly explosive-looking compound..

Of course, "explosive" is not a spectroscopically relevant argument. Nevertheless, maybe we should check out one obvious and two less obvious permutation possibilities first.

The easiest way seems to be the exchange of – O – und – CO –. Let's try this out.



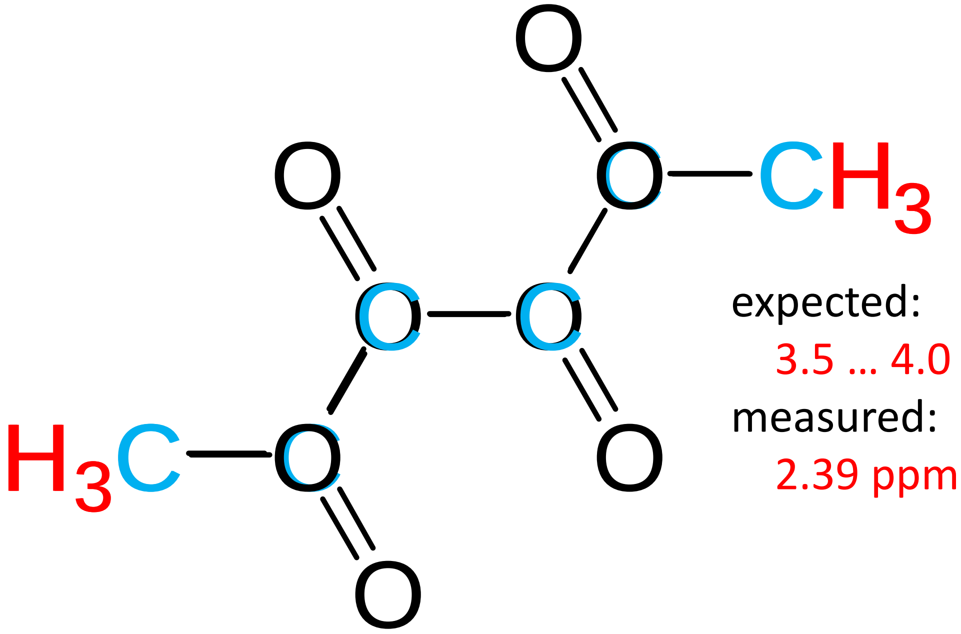
H : 2.39 ppm C : 36.92 ppm C : 185.20 ppm

Doing this intra-molecular exchange, we get oxalic acid dimethyl ester, a very commonly used compound.

Unfortunately, this compound does not match the measured chemical shifts. A quick check using an overview table of chemical shifts, found in many books on NMR spectroscopy, suggests a chemical shift of 3.5 ... 4.0 ppm for the protons of the methoxy group..

That’s a significant difference to the measured value of 2.39 ppm.

But we can still exchange some more atoms, even if this is not obvious at first sight. First of all, let’s rewrite the methyl groups a little bit. For sure, normally you wouldn’t write a methyl group this way.



expected:
3.5 … 4.0 ppm
measured:
2.39 ppm

H : 2.39 ppm C : 36.92 ppm C : 185.20 ppm

Using this somewhat strange notation, the fragments – CH_2 – and – O – now offer themselves for mutual exchange.

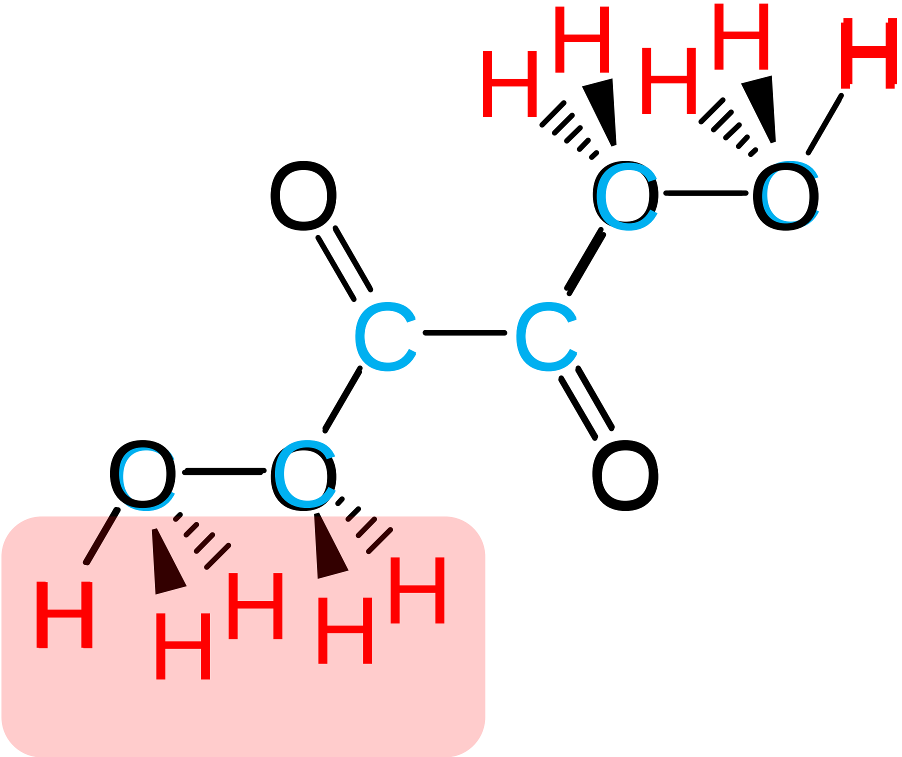
But ... now there are two different proton groups in the integral ratio **2 : 1**?

At this point we should revisit all available pieces of information. There is a small detail, nearly always without of interest.

Solvent: **D2O**!

What does this mean?

The concentration of the sample might be 10 mMol, so that the concentration of OH groups is 20 mMol. The concentration of OD groups in D_2O is 110 moles (not “milli”).
Because of the large excess of deuterium, the chemically exchangeable OH protons are almost completely converted into OD groups, which show no signal in the proton spectrum.



Translation in progress

Last processing status: 7th of September 2022

H : 2.39 ppm

C : 36.92 ppm

C : 185.20 ppm

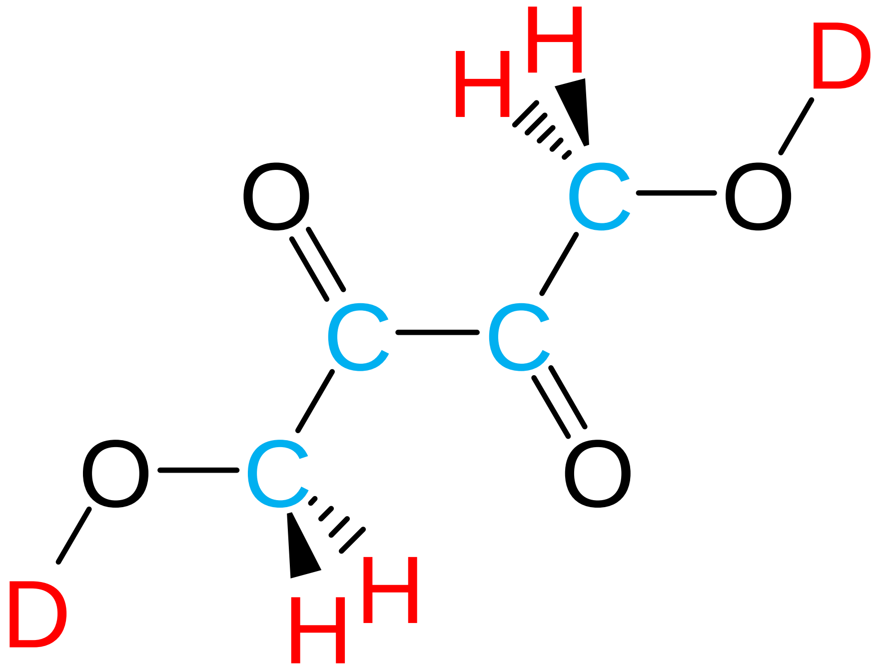
Of course, the OH protons have not disappeared. They are now part of the HOD signal at about 4.7 ppm and thus not in the range shown here.

The Schoolery rule can be used to estimate the chemical shift of the methylene protons. The calculation gives us

$$\delta(\mathrm{CH_2}) = 1.70\ \mathrm{ppm} + 2.56\ \mathrm{ppm} = 4.26\ \mathrm{ppm}$$

and thus deviates almost 2 ppm from the measured value (2.39 ppm, see sticky note).

But there is a last permutation possibility.



H : 2.39 ppm

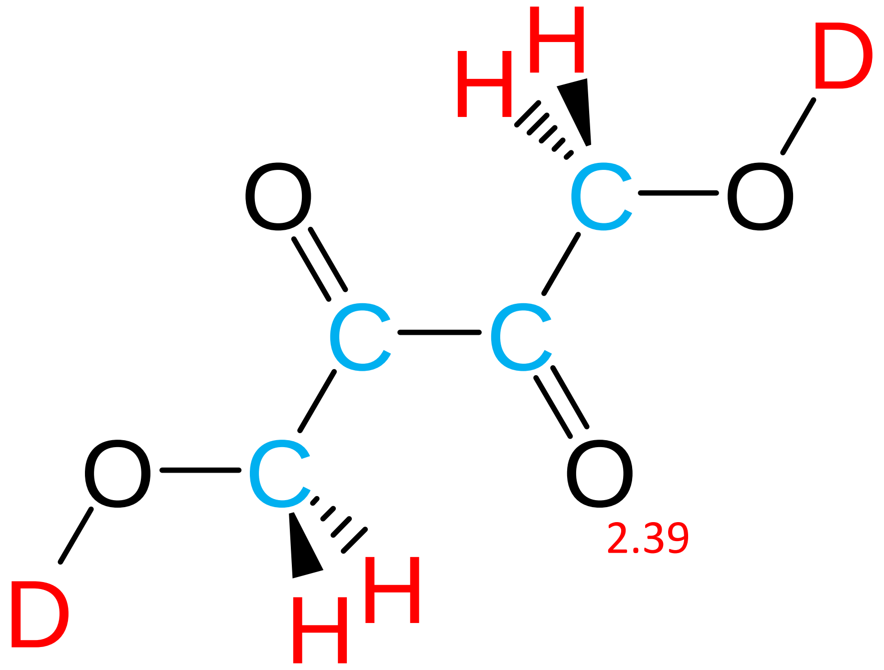
C : 36.92 ppm

C : 185.20 ppm

A new estimation of the chemical shift of the methylene protons using the Schoolery rule now gives

$$\delta(CH_2) = 0.47 \text{ ppm} + 1.55 \text{ ppm} = 2.12 \text{ ppm}$$

which is very close to the measured value (2.39 ppm, see sticky note).

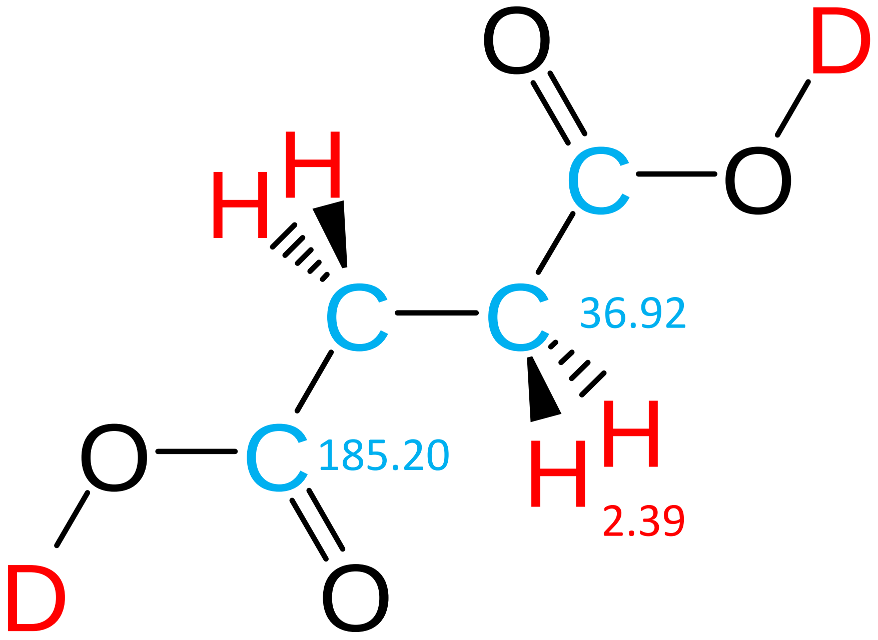


C : 36.92 ppm

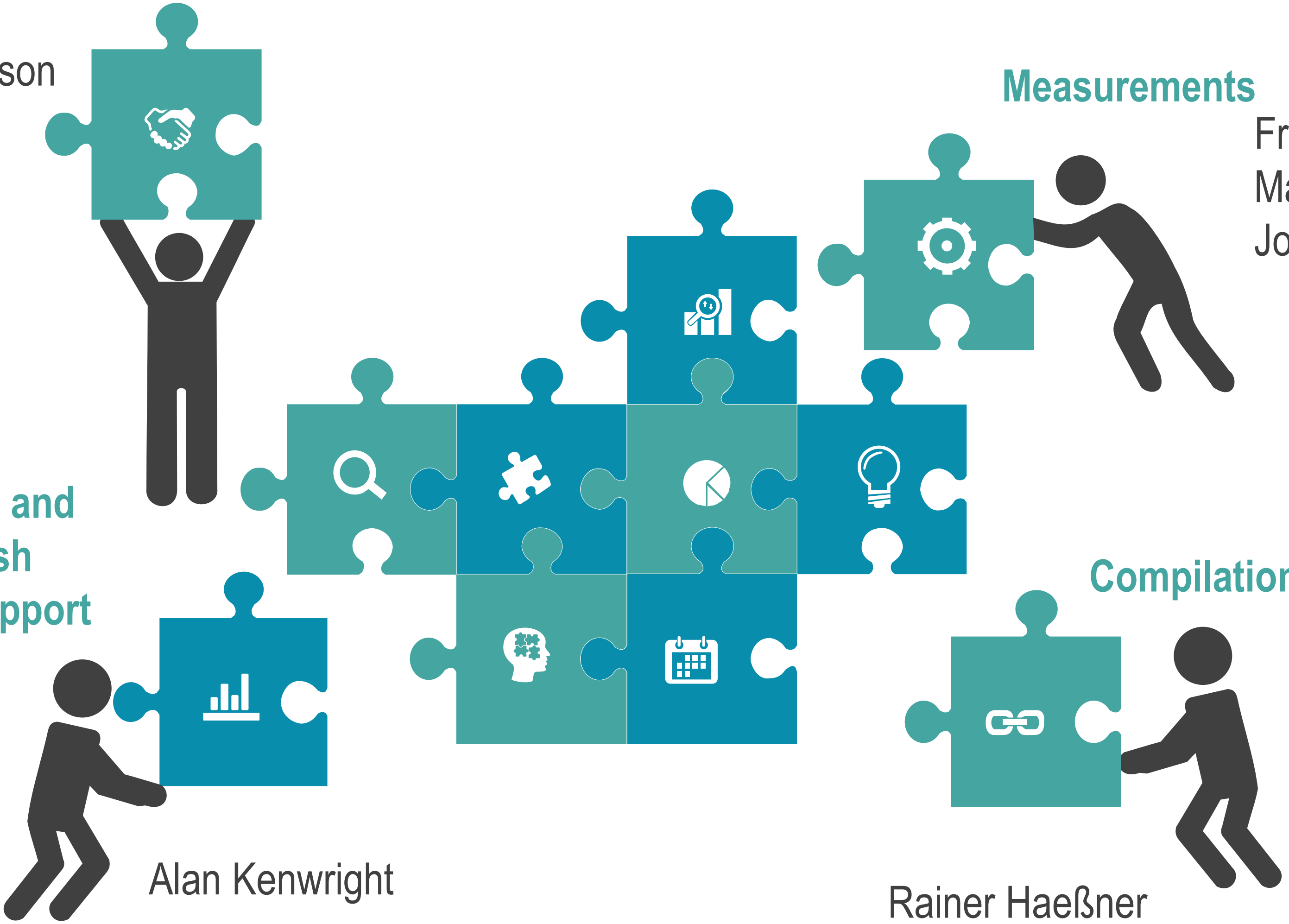
C : 185.20 ppm

It should be easy to assign the carbon signals.

Because of the chemical exchange between succinic acid and the solvent there is no assignments possible for the OH/OD groups.



Contributions



Spectrometer time

University of Wisconsin-Madison
(BioMagResBank)

Measurements

Francisca Jofre,
Mark E. Anderson,
John L. Markley

Discussions and native English language support

Alan Kenwright

Compilation

Rainer Haeßner

[More exercises …]