

IAPWS

0.1

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Chapter 1

Introduction

`ipaws` is a Fortran library providing the formulas for computing light and heavy water properties. It also provides a API for the C language. The formulations are taken from <http://iapws.org>. A shared and a static library `libiapws` are compiled (f2008+) with the Fortran and C headers. The static and shared libraries can be installed in order to be included in Fortran or C programs.

The compilation was tested on Linux (Debian), MacOS and Windows.

Links:

- Sources: [(<https://github.com/MilanSkocic/iapws>).
- Online documentation: [(<https://milanskocic.github.io/iapws/iapws/index.html>).
- PDF documentation: [(<https://milanskocic.github.io/iapws/iapws/refman.pdf>).
- Python wrapper: [(<https://milanskocic.github.io/iapws/pyiapws/index.html>).

1.1 Installation

See the file `INSTALL`.

1.2 Dependencies

See the file `REQUIREMENTS`.

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Chapter 2

IAPWS G7-04

The computation is based on the parameters provided by the IAPWS 2004: $k_H = \lim_{x_2 \rightarrow 0} f_2/x_2$.

where f_2 and x_2 are, respectively, the liquid-phase fugacity and mole fraction of the solute.

The Henry's constant k_H is given as a function of temperature by:

$$\ln \left(\frac{k_H}{p_1^*} \right) = A/T_R + \frac{B \cdot \tau^{0.355}}{T_R} + C \cdot T_R^{-0.41} \cdot \exp \tau$$
$$\tau = 1 - T_R$$
$$T_R = T/T_{c1}$$

- T_{c1} is the critical temperature of the solvent as recommended by IAPWS1997 (647.096 for H₂O and 643.847 K for D₂O) and p_1^* is the vapor pressure of the solvent at the temperature of interest.
- p_1^* is calculated from the correlation of Wagner and Pruss for H₂O and from the correlation of Harvey and Lemmon for D₂O.

Both equations have the form $\ln(p_1^*/p_{c1}) = T_R^{-1} \sum_{i=1}^n a_i \tau^{b_i}$ where the number of terms n is 6 for H₂O and 5 for D₂O, p_{c1} is the critical pressure of the solvent recommended by IAPWS IAPWS1997 (22.064 MPa for H₂O and 21.671 MPa for D₂O)

The Henry's constant : k_H has a dimension of pressure expressed here in bars:

$$x_2[\text{mole fraction per bar}] = \frac{1}{k_H}$$
$$S[\text{ppm} \cdot \text{bar}^{-1}] = \frac{x_2 \cdot M_{gas}}{M_s} \cdot 10^6$$
$$S[\text{cm}^3 \cdot \text{kg}^{-1} \cdot \text{bar}^{-1}] = \frac{x_2 \cdot V_m}{M_s}$$

See also

Guideline on the Henry's Constant and Vapor-Liquid Distribution Constant for Gases in H₂O and D₂O at High Temperatures », IAPWS, Kyoto, Japan, G7-04, 2004

Revised Release on the IAPWS Industrial Formulation 1997 for the thermodynamic Properties of Water and Steam, IAPWS, Lucerne Switzerland R7-97, 2012.

W. Wagner et A. Pruss, « International Equations for the Saturation Properties of Ordinary Water Substance. Revised According to the International Temperature Scale of 1990. Addendum to J. Phys. Chem. Ref. Data 16, 893 (1987) », Journal of Physical and Chemical Reference Data, vol. 22, n°3, p. 783-787, mai 1993.

<https://doi.org/10.1063/1.555926>

A. H. Harvey et E. W. Lemmon, « Correlation for the Vapor Pressure of Heavy Water From the Triple Point to the Critical Point », Journal of Physical and Chemical Reference Data, vol. 31, n°1, p. 173-181, mars 2002

<https://doi.org/10.1063/1.1430231>

Chapter 3

Installation

3.1 Create build directory

- `mkdir build`
- `cd build`

3.2 Generate a makefile

- On Unix-like OS: `cmake -G "Unix Makefiles" -S .. -DCMAKE_BUILD_TYPE=release -DCMAKE_INSTALL_PREFIX=/path/to/folder`
- On windows with MSYS2: `cmake -G "Unix Makefiles" -S .. -DCMAKE_BUILD_TYPE=release -DCMAKE_INSTALL_PREFIX=/path/to/folder`
- On windows with ifort and msvc: `cmake -G "NMake Makefiles" -S .. -DCMAKE_BUILD_TYPE=release -DCMAKE_INSTALL_PREFIX=/path/to/folder`

3.3 Build either with cmake

```
cmake --build .
```

3.4 Run tests

```
ctest
```

3.5 Install

```
cmake --install .
```


Chapter 4

license

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```
<program> Copyright (C) <year> <name of author>
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```

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Chapter 5

requirements

gcc \geq 10.0

gfortran \geq 10.0

cmake \geq 3.10

Chapter 6

Modules Index

6.1 Modules List

Here is a list of all documented modules with brief descriptions:

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File Index

7.1 File List

Here is a list of all documented files with brief descriptions:

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Chapter 8

Module Documentation

8.1 iapws Module Reference

Main module for IAPWS computations.

Functions/Subroutines

- pure real(real64) function, public [iapws_kh](#) (T, gas, solvent)
Compute the henry constant for a given temperature and gas in solvent.
- pure real(real64) function, public [iapws_scm3](#) (T, gas, solvent)
Compute the solubility for a given temperature and gas in solvent.
- pure real(real64) function, public [iapws_sppm](#) (T, gas, solvent)
Compute the solubility for a given temperature and gas in solvent.

8.1.1 Detailed Description

Main module for IAPWS computations.

8.1.2 Function/Subroutine Documentation

8.1.2.1 iapws_kh()

```
pure real(real64) function, public iapws::iapws_kh (  
    real(real64), intent(in) T,  
    character(len=*), intent(in) gas,  
    character(len=*), intent(in) solvent )
```

Compute the henry constant for a given temperature and gas in solvent.

Parameters

in	<i>T</i>	Temperature in °C.
in	<i>gas</i>	Gas.
in	<i>solvent</i>	Solvents: H2O or D2O. Default is H2O.

Returns

kh Henry constant in mole fraction per GPa. NaN if gas not found.

8.1.2.2 iapws_scm3()

```
pure real(real64) function, public iapws::iapws_scm3 (
    real(real64), intent(in) T,
    character(len=*), intent(in) gas,
    character(len=*), intent(in) solvent )
```

Compute the solubility for a given temperature and gas in solvent.

Parameters

in	<i>T</i>	Temperature in °C.
in	<i>gas</i>	Gas.
in	<i>solvent</i>	Solvents: H2O or D2O. Default is H2O.

Returns

Scm3 Solubility constant in cm3.kg-1.bar-1. NaN if gas not found.

8.1.2.3 iapws_sppm()

```
pure real(real64) function, public iapws::iapws_sppm (
    real(real64), intent(in) T,
    character(len=*), intent(in) gas,
    character(len=*), intent(in) solvent )
```

Compute the solubility for a given temperature and gas in solvent.

Parameters

in	<i>T</i>	Temperature in °C.
in	<i>gas</i>	Gas.
in	<i>solvent</i>	Solvents: H2O or D2O. Default is H2O.

Returns

Sppm Solubility constant in ppm. NaN if gas not found.

8.2 iapws_capi Module Reference

C API for the IAPWS module.

Functions/Subroutines

- `real(c_double)` function, public `iapws_capi_kh` (`T`, `gas`, `solvent`, `size_gas`, `size_solvent`)
Compute the henry constant for a given temperature and gas in solvent.
- `real(c_double)` function, public `iapws_capi_scm3` (`T`, `gas`, `solvent`, `size_gas`, `size_solvent`)
Compute the solubility constant for a given temperature and gas in solvent.
- `real(c_double)` function, public `iapws_capi_sppm` (`T`, `gas`, `solvent`, `size_gas`, `size_solvent`)
Compute the solubility constant for a given temperature and gas in solvent.

8.2.1 Detailed Description

C API for the IAPWS module.

8.2.2 Function/Subroutine Documentation

8.2.2.1 iapws_capi_kh()

```
real(c_double) function, public iapws_capi::iapws_capi_kh (
    real(c_double), value T,
    type(c_ptr), intent(in), value gas,
    type(c_ptr), intent(in), value solvent,
    integer(c_int), intent(in), value size_gas,
    integer(c_int), intent(in), value size_solvent )
```

Compute the henry constant for a given temperature and gas in solvent.

Parameters

in	<i>T</i>	Temperature in °C.
in	<i>gas</i>	Gas.
in	<i>solvent</i>	Solvents: H2O or D2O. Default is H2O.
in	<i>size_gas</i>	Length of the string gas.
in	<i>size_solvent</i>	Length of the string gas.

Returns

kh Henry constante in mole fraction per GPa. NaN if gas not found.

8.2.2.2 iapws_capi_scm3()

```
real(c_double) function, public iapws_capi::iapws_capi_scm3 (
    real(c_double), intent(in), value T,
    type(c_ptr), intent(in), value gas,
    type(c_ptr), intent(in), value solvent,
    integer(c_int), intent(in), value size_gas,
    integer(c_int), intent(in), value size_solvent )
```

Compute the solubility constant for a given temperature and gas in solvent.

Parameters

in	<i>T</i>	Temperature in °C.
in	<i>gas</i>	Gas.
in	<i>solvent</i>	Solvents: H2O or D2O. Default is H2O.
in	<i>size_gas</i>	Length of the string gas.
in	<i>size_solvent</i>	Length of the string gas.

Returns

Scm3 Solubility constant in cm3.kg-1.bar-1. NaN if gas not found.

8.2.2.3 iapws_capi_sppm()

```
real(c_double) function, public iapws_capi::iapws_capi_sppm (
    real(c_double), intent(in), value T,
    type(c_ptr), intent(in), value gas,
    type(c_ptr), intent(in), value solvent,
    integer(c_int), intent(in), value size_gas,
    integer(c_int), intent(in), value size_solvent )
```

Compute the solubility constant for a given temperature and gas in solvent.

Parameters

in	<i>T</i>	Temperature in °C.
in	<i>gas</i>	Gas.
in	<i>solvent</i>	Solvents: H2O or D2O. Default is H2O.
in	<i>size_gas</i>	Length of the string gas.
in	<i>size_solvent</i>	Length of the string gas.

Returns

Sppm Solubility constant in ppm. NaN if gas not found.

8.3 iapwsg704 Module Reference

Module for IAPWS G7-04.

Functions/Subroutines

- pure real(real64) function, public [iapwsg704_kh_water](#) (T, gas)
Compute the henry constante for a given temperature and gas in water.
- pure real(real64) function, public [iapwsg704_kh_heavywater](#) (T, gas)
Compute the henry constante for a given temperature and gas in heavywater.
- pure real(real64) function, public [iapwsg704_kh_scm3_water](#) (T, gas)
Compute the solubility for a given temperature and gas in water.
- pure real(real64) function, public [iapwsg704_kh_scm3_heavywater](#) (T, gas)
Compute the solubility for a given temperature and gas in heavywater.
- pure real(real64) function, public [iapwsg704_kh_sppm_water](#) (T, gas)
Compute the solubility for a given temperature and gas in water.
- pure real(real64) function, public [iapwsg704_kh_sppm_heavywater](#) (T, gas)
Compute the solubility for a given temperature and gas in heavywater.

8.3.1 Detailed Description

Module for IAPWS G7-04.

8.3.2 Function/Subroutine Documentation

8.3.2.1 iapwsg704_kh_heavywater()

```
pure real(real64) function, public iapwsg704::iapwsg704_kh_heavywater (
    real(real64), intent(in) T,
    character(len=*), intent(in) gas )
```

Compute the henry constante for a given temperature and gas in heavywater.

Parameters

in	<i>T</i>	Temperature in °C.
in	<i>gas</i>	Gas.

Returns

kh Henry constante in mole fraction per GPa. NaN if gas not found.

8.3.2.2 iapwsg704_kh_scm3_heavywater()

```
pure real(real64) function, public iapwsg704::iapwsg704_kh_scm3_heavywater (
    real(real64), intent(in) T,
    character(len=*), intent(in) gas )
```

Compute the solubility for a given temperature and gas in heavywater.

Parameters

in	<i>T</i>	Temperature in °C.
in	<i>gas</i>	Gas.

Returns

Scm3 Solubility constant in cm3.kg-1.bar-1. NaN if gas not found.

8.3.2.3 iapwsg704_kh_scm3_water()

```
pure real(real64) function, public iapwsg704::iapwsg704_kh_scm3_water (
    real(real64), intent(in) T,
    character(len=*), intent(in) gas )
```

Compute the solubility for a given temperature and gas in water.

Parameters

in	<i>T</i>	Temperature in °C.
in	<i>gas</i>	Gas.

Returns

Scm3 Solubility constant in cm3.kg-1.bar-1. NaN if gas not found.

8.3.2.4 iapwsg704_kh_sppm_heavywater()

```
pure real(real64) function, public iapwsg704::iapwsg704_kh_sppm_heavywater (
    real(real64), intent(in) T,
    character(len=*), intent(in) gas )
```

Compute the solubility for a given temperature and gas in heavywater.

Parameters

in	T	Temperature in °C.
in	<i>gas</i>	Gas.

Returns

Sppm Solubility constant in ppm. NaN if gas not found.

8.3.2.5 iapwsg704_kh_sppm_water()

```
pure real(real64) function, public iapwsg704::iapwsg704_kh_sppm_water (
    real(real64), intent(in) T,
    character(len=*), intent(in) gas )
```

Compute the solubility for a given temperature and gas in water.

Parameters

in	T	Temperature in °C.
in	<i>gas</i>	Gas.

Returns

Sppm Solubility constant in ppm. NaN if gas not found.

8.3.2.6 iapwsg704_kh_water()

```
pure real(real64) function, public iapwsg704::iapwsg704_kh_water (
    real(real64), intent(in) T,
    character(len=*), intent(in) gas )
```

Compute the henry constante for a given temperature and gas in water.

Parameters

in	T	Temperature in °C.
in	<i>gas</i>	Gas.

Returns

kh Henry constante in mole fraction per GPa. NaN if gas not found.

Chapter 9

File Documentation

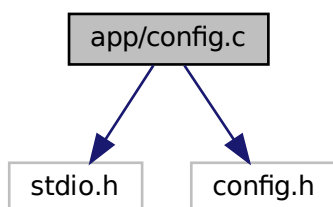
9.1 app/config.c File Reference

Provides the configuration of the iapws library.

```
#include <stdio.h>
```

```
#include "config.h"
```

Include dependency graph for config.c:



Functions

- `int main (int argc, char **argv)`
Prints the configuration for the iapws library.

9.1.1 Detailed Description

Provides the configuration of the iapws library.

9.2 src/iapws.f90 File Reference

Main module for IAPWS.

Modules

- module [iapws](#)
Main module for IAPWS computations.

Functions/Subroutines

- pure real(real64) function, public [iapws::iapws_kh](#) (T, gas, solvent)
Compute the henry constant for a given temperature and gas in solvent.
- pure real(real64) function, public [iapws::iapws_scm3](#) (T, gas, solvent)
Compute the solubility for a given temperature and gas in solvent.
- pure real(real64) function, public [iapws::iapws_sppm](#) (T, gas, solvent)
Compute the solubility for a given temperature and gas in solvent.

9.2.1 Detailed Description

Main module for IAPWS.

9.3 src/iapws.h File Reference

C header for the IAPWS library.

Functions

- double [iapws_capi_kh](#) (double T, char *gas, char *solvent, int size_gas, int size_solvent)
Compute the henry constante for a given temperature and gas in solvent.
- double [iapws_capi_scm3](#) (double T, char *gas, char *solvent, int size_gas, int size_solvent)
Compute the solubility constant for a given temperature and gas in solvent.
- double [iapws_capi_sppm](#) (double T, char *gas, char *solvent, int size_gas, int size_solvent)
Compute the solubility constant for a given temperature and gas in solvent.

9.3.1 Detailed Description

C header for the IAPWS library.

9.3.2 Function Documentation

9.3.2.1 iapws_capi_kh()

```
double iapws_capi_kh (
    double T,
    char * gas,
    char * solvent,
    int size_gas,
    int size_solvent )
```

Compute the henry constante for a given temperature and gas in solvent.

Parameters

in	<i>T</i>	Temperature in °C.
in	<i>gas</i>	Gas.
in	<i>solvent</i>	Solvents: H2O or D2O. Default is H2O.
in	<i>size_gas</i>	Length of gas string
in	<i>size_solvent</i>	Length of solvent string

Returns

kh Henry constante in mole fraction per GPa. NaN if gas not found.

Examples

[example_in_c.c.](#)

9.3.2.2 iapws_capi_scm3()

```
double iapws_capi_scm3 (  
    double T,  
    char * gas,  
    char * solvent,  
    int size_gas,  
    int size_solvent )
```

Compute the solubility constant for a given temperature and gas in solvent.

Parameters

in	<i>T</i>	Temperature in °C.
in	<i>gas</i>	Gas.
in	<i>solvent</i>	Solvents: H2O or D2O. Default is H2O.
in	<i>size_gas</i>	Length of gas string
in	<i>size_solvent</i>	Length of solvent string

Returns

Scm3 Solubility constant in cm3.kg-1.bar-1. Nan if gas not found.

Examples

[example_in_c.c.](#)

9.3.2.3 iapws_capi_sppm()

```
double iapws_capi_sppm (
    double T,
    char * gas,
    char * solvent,
    int size_gas,
    int size_solvent )
```

Compute the solubility constant for a given temperature and gas in solvent.

Parameters

in	<i>T</i>	Temperature in °C.
in	<i>gas</i>	Gas.
in	<i>solvent</i>	Solvents: H2O or D2O. Default is H2O.
in	<i>size_gas</i>	Length of gas string
in	<i>size_solvent</i>	Length of solvent string

Returns

Sppm Solubility constant in ppm. Nan if gas not found.

Examples

[example_in_c.c.](#)

9.4 src/iapws_capi.f90 File Reference

C API for the IAPWS module.

Modules

- module [iapws_capi](#)
C API for the IAPWS module.

Functions/Subroutines

- real(c_double) function, public [iapws_capi::iapws_capi_kh](#) (T, gas, solvent, size_gas, size_solvent)
Compute the henry constant for a given temperature and gas in solvent.
- real(c_double) function, public [iapws_capi::iapws_capi_scm3](#) (T, gas, solvent, size_gas, size_solvent)
Compute the solubility constant for a given temperature and gas in solvent.
- real(c_double) function, public [iapws_capi::iapws_capi_sppm](#) (T, gas, solvent, size_gas, size_solvent)
Compute the solubility constant for a given temperature and gas in solvent.

9.4.1 Detailed Description

C API for the IAPWS module.

9.5 src/iapwsG704.f90 File Reference

Module for IAPWS G7_04.

Modules

- module [iapwsg704](#)
Module for IAPWS G7-04.

Functions/Subroutines

- pure real(real64) function, public [iapwsg704::iapwsg704_kh_water](#) (T, gas)
Compute the henry constante for a given temperature and gas in water.
- pure real(real64) function, public [iapwsg704::iapwsg704_kh_heavywater](#) (T, gas)
Compute the henry constante for a given temperature and gas in heavywater.
- pure real(real64) function, public [iapwsg704::iapwsg704_kh_scm3_water](#) (T, gas)
Compute the solubility for a given temperature and gas in water.
- pure real(real64) function, public [iapwsg704::iapwsg704_kh_scm3_heavywater](#) (T, gas)
Compute the solubility for a given temperature and gas in heavywater.
- pure real(real64) function, public [iapwsg704::iapwsg704_kh_sppm_water](#) (T, gas)
Compute the solubility for a given temperature and gas in water.
- pure real(real64) function, public [iapwsg704::iapwsg704_kh_sppm_heavywater](#) (T, gas)
Compute the solubility for a given temperature and gas in heavywater.

9.5.1 Detailed Description

Module for IAPWS G7_04.

Chapter 10

Example Documentation

10.1 example_in_f.f90

```
1 program example_in_f
2   use iso_fortran_env
3   use iapws
4   implicit none
5   real(real64) :: kh, Scm3, Sppm
6   integer(int32) :: status
7   character(len=5) :: gas = "O2"
8   character(len=5) :: solvent = "H2O"
9   real(real64) :: T = 25.0d0
10
11   kh = iapws_kh(t, gas, solvent)
12   print "(A10, X, A10, X, A2, F10.1, A, 4X, A3, SP, F10.4)", "Gas=", gas, "T=", t, "C", "kh=", kh
13   scm3 = iapws_scm3(t, gas, solvent)
14   print "(A10, X, A10, X, A2, F10.1, A, 4X, A3, SP, F10.4, A20)", "Gas=", gas, "T=", t, "C", "kh=",
15     scm3, " cm3.kg-1.bar-1"
16   sppm = iapws_sppm(t, gas, solvent)
17   print "(A10, X, A10, X, A2, F10.1, A, 4X, A3, SP, F10.4, A20)", "Gas=", gas, "T=", t, "C", "kh=",
18     sppm, " ppm.bar-1"
19 end program
```

10.2 example_in_c.c

```
#include <string.h>
#include <stdio.h>
#include "iapws.h"
int main(int argc, char **argv){
    double T = 25.0; /* in C*/
    char *gas = "O2";
    char *solvent = "H2O";
    double kh, Scm3, Sppm;

    if(argc > 1 ){
        printf("%s\n", argv[1]);
    }
    kh = iapws_capi_kh(T, gas, solvent, strlen(gas), strlen(solvent));
    Scm3 = iapws_capi_scm3(T, gas, solvent, strlen(gas), strlen(solvent));
    Sppm = iapws_capi_sppm(T, gas, solvent, strlen(gas), strlen(solvent));
    printf("Gas=%s\tT=%f°C\tkh=%+10.4f\n", gas, T, kh);
    printf("Gas=%s\tT=%f°C\tS=%+10.4f cm3.kg-1.bar-1\n", gas, T, Scm3);
    printf("Gas=%s\tT=%f°C\tS=%+10.4f ppm.bar-1\n", gas, T, Sppm);

    return 0;
}
```


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