

## **iapws**

### **Table of Contents**

iapws . . . . .	1
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**NAME**

**iapws** - Compute light and heavy water properties.

**SYNOPSIS**

**iapws** *SUBCOMMAND* [*OPTION...*]

**DESCRIPTION**

**iapws** is a command line interface which computes the properties of light and heavy water according to IAPWS.

**SUBCOMMANDS**

Valid subcommands are:

- +kh**     Compute the Henry's constant for gases in H<sub>2</sub>O or D<sub>2</sub>O. The default behavior is to compute the constant kH for O<sub>2</sub> at 25Â°C. See options.
- +kd**     Compute the vapor-liquid distribution constant for gases in H<sub>2</sub>O or D<sub>2</sub>O. The default behavior is to compute the constant kD for H<sub>2</sub> at 25Â°C. See options.

Their syntax is:

- +kh**     [OPTION...]
- +kd**     [OPTION...]

**OPTIONS**

kh:

- temperature, -T TEMPERATURE...**  
Temperature in Â°C. Default to 25Â°C.
- fugacity, -f FUGACITY...**  
Liquid-phase fugacity in MPa. Default to 0.1
- gases, -g GAS...**  
Gases for which to compute kH. Default to O<sub>2</sub>
- D2O**   Set heavywater as the solvent.
- listgases**  
Display available gases for computing kH.

kd:

- temperature, -T TEMPERATURE...**  
Temperature in Â°C. Default to 25Â°C.
- x2, -x x2...**  
Molar fraction of gas in water. Default to 1
- gases, -g GAS...**  
Gases for which to compute kD. Default to H<sub>2</sub>
- D2O,** Set heavywater as the solvent.
- listgases**  
Display available gases for computing kD.

all:

- usage, -u**  
Show usage text and exit.
- help, -h**  
Show help text and exit.

**--verbose, -V**

Display additional information when availabl

**--version, -v**

Show version information and exit.

## EXAMPLE

Minimal example

```
iapws kh -T 25,100 -f 0.1,0.02 -g O2,H2
```

```
iapws kd -T 25,100 -x2 1d-9,1d-6 -g O2,H2
```

## SEE ALSO

**ciaaw(3), codata(3)**

**NAME**

**iapws** - library for light and heavy water properties according to IAPWS.

**LIBRARY**

iapws (-libiapws, -lipaws)

**SYNOPSIS**

```
use iapws
include "iapws.h"
import pyiapws
```

**DESCRIPTION**

Numerical implementation for reports:

- R2-83
  - [x] Tc in H2O and D2O
  - [x] pc in H2O and D2O
  - [x] rhoc in H2O and D2O
- G7-04
  - [x] kH
  - [x] kD
- R7-97
  - [x] Region 1
  - [ ] Region 2
  - [ ] Region 3
  - [x] Region 4
  - [ ] Region 5
- R11-24:
  - [x] Kw

Fortran API

```
o real(dp), parameter :: Tc_H2O = 647.096_dp
    Critical temperature for H2O in K
o real(dp), parameter :: Tc_D2O = 643.847_dp
    Critical temperature for D2O in K
o real(dp), parameter :: pc_H2O = 22.064_dp
    Critical pressure for H2O in MPa
o real(dp), parameter :: pc_D2O = 21.671_dp
    Critical pressure for H2O in MPa
o real(dp), parameter :: rhoc_H2O = 322.0_dp
    Critical density for H2O in kg.m-3
o real(dp), parameter :: rhoc_D2O = 356.0_dp
    Critical density for H2O in kg.m-3
o function get_version()result(fpstr)
    Return the version
o character(len=:), pointer :: fpstr
    Fortran pointer to a string indicating the version.
```

- o pure subroutine kh(T, gas, heavywater, k)**  
Compute the henry constant kH in MPa for a given temperature ( $x_2=1/kH$ ).
  - o real(dp), intent(in), contiguous :: T(:)**  
Temperature in K.
  - o character(len=\*), intent(in) :: gas**  
Gas.
  - o integer(int32), intent(in) :: heavywater**  
Flag if D2O (1) is used or **H2O**(0).
  - o real(dp), intent(out), contiguous :: k(:)**  
Henry constant in MPa. Filled with NaNs if gas not found.
- o pure subroutine kd(T, gas, heavywater, k)**  
Compute the vapor-liquid constant kd for a given temperature ( $kd=y_2/x_2$ ).
  - o real(dp), intent(in), contiguous :: T(:)**  
Temperature in K.
  - o character(len=\*), intent(in) :: gas**  
Gas.
  - o integer(int32), intent(in) :: heavywater**  
Flag if D2O (1) is used or **H2O**(0).
  - o real(dp), intent(out), contiguous :: k(:)**  
Vapor-liquid constant (adimensional). Filled with NaNs if gas not found.
- o pure function ngases(heavywater)result(n)**  
Returns the number of gases.
  - o integer(int32), intent(in) :: heavywater**  
Flag if D2O (1) is used or **H2O**(0).
  - o integer(int32) :: n**  
Number of gases.
- o function gases(heavywater)result(list\_gases)**  
Returns the list of available gases.
  - o integer(int32), intent(in) :: heavywater**  
Flag if D2O (1) is used or **H2O**(0).
  - o type(gas\_type), pointer :: list\_gases(:)**  
Available gases.
- o function gases2(heavywater)result(str\_gases)**  
Returns the available gases as a string.
  - o integer(int32), intent(in) :: heavywater**  
Flag if D2O (1) is used or **H2O**(0).
  - o character(len=:), pointer :: str\_gases**  
Available gases
- o pure subroutine psat(Ts, ps)**  
Compute the saturation pressure at temperature Ts ( $273.13\text{ K} \leq Ts \leq 647.096\text{ K}$ ).
  - o real(dp), intent(in), contiguous :: Ts(:)**  
Saturation temperature in K.
  - o real(dp), intent(out), contiguous :: ps(:)**  
Saturation pressure in MPa. Filled with nan if out of validity range.

**o pure subroutine Tsat(ps, Ts)**

Compute the saturation temperature at pressure ps (611.213 Pa <= ps <= 22.064 MPa).

**o real(dp), intent(in), contiguous :: ps(:)**

Saturation pressure in MPa.

**o real(dp), intent(out), contiguous :: Ts(:)**

Saturation temperature in K. Filled with nan if out of validity range.

**o pure subroutine wp(p, T, prop, res)**

Compute water properties at pressure p in MPa and temperature T in Kelvin.

**o real(dp), intent(in) :: p(:)**

Pressure in MPa.

**o real(dp), intent(in) :: T(:)**

Pressure in K.

**o character(len=\*), intent(in) :: prop**

Property (v, u, s, h, cp, cv, w)

**o real(dp), intent(out) :: res(:)**

Filled with NaN if no adequate region is found.

**o pure subroutine wr(p, T, res)**

Get the water region corresponding to p and T.

**o real(dp), intent(in) :: p(:)**

Pressure in MPa.

**o real(dp), intent(in) :: T(:)**

Temperature in K.

**o integer(int32), intent(out) :: res(:)**

Region 1 to 5 if found or -1.

**o pure subroutine wph(p, T, res)**

Get the water phase corresponding to p and T.

**o real(dp), intent(in) :: p(:)**

pressure in MPa.

**o real(dp), intent(in) :: T(:)**

Temperature in K.

**o character(len=1), intent(out) :: res(:)**

Phases: l(liquid), v(VAPOR), c(SUPER CRITICAL), s(SATURATION), n(UNKNOWN).

**o pure subroutine Kw(T, rhow, k)**

Compute the ionization constant of water Kw (273.13 K <= T <= 1273.15 K and 0 <= p <= 1000 MPa).

**o real(dp), intent(in) :: T(:)**

Temperature in K.

**o real(dp), intent(in) :: rhow(:)**

Mass density in g.cm<sup>-3</sup>.

**o real(dp), intent(out) :: k(:)**

Ionization constant. Filled with NaN if out of validity range.

## C API

- char\* iapws\_get\_version(void)

- `const double iapws_r283_Tc_H2O`
- `const double iapws_r283_Tc_D2O`
- `const double iapws_r283_pc_H2O`
- `const double iapws_r283_pc_D2O`
- `const double iapws_r283_rhoc_H2O`
- `const double iapws_r283_rhoc_D2O`
- `void iapws_g704_kh(double *T, char *gas, int heavywater, double *k, int size_gas, size_t size_T)`
- `void iapws_g704_kd(double *T, char *gas, int heavywater, double *k, int size_gas, size_t size_T)`
- `int iapws_g704_ngases(int heavywater)`
- `char **iapws_g704_gases(int heavywater)`
- `char *iapws_g704_gases2(int heavywater)`
- `void iapws_r797_psat(size_t N, double *Ts, double *ps)`
- `void iapws_r797_Tsat(size_t N, double *ps, double *Ts)`
- `void iapws_r797_wp(double *p, double *T, char *prop, double *res, size_t N, size_t len)`
- `void iapws_r797_wr(double *p, double *T, int *res, size_t N)`
- `void iapws_r797_wph(double *p, double *T, char *res, size_t N)`
- `void iapws_r1124_Kw(size_t N, double *T, double *rhow, double *k)`

Python wrapper

- `kh(T: np.ndarray, gas: str, heavywater: bool=False)->Union[np.ndarray, float]`
- `kd(T: np.ndarray, gas: str, heavywater: bool=False)->Union[np.ndarray, float]`
- `ngases(heavywater:bool=False)->int`
- `gases(heavywater: bool=False)->List[str]`
- `gases2(heavywater: bool=False)->str`
- `psat(Ts)->Union[np.ndarray, float]`
- `Tsat(ps)->Union[np.ndarray, float]`
- `wp(p, T, prop)->Union[np.ndarray, float]`
- `wr(p, T)->Union[np.ndarray, float]`
- `wph(p, T)->Union[np.ndarray, str]`
- `Kw(T: np.ndarray, rhow: np.ndarray)->Union[np.ndarray, float]`

## NOTES

To use *iapws* within your fpm project, add the following to your fpm.toml file:

```
[dependencies]
iapws = { git="https://github.com/MilanSkocic/iapws.git" }
```

- `dp` stands for double precision and it is an alias to `real64` from the `iso_fortran_env` module.
- `l` => liquid
- `v` => vapor

- c => super critical
- s => saturation
- n => unknown

**EXAMPLE**

Example in Fortran

```

program example_in_f
use stdlib_kinds, only: dp, int32
use iapws
implicit none
integer(int32) :: i, ngas
real(dp) :: T(1), kh_res(1), kd_res(1), wp_res(1), p(1)
real(dp) :: Ts(7), ps(7)
real(dp) :: x(3), y(3)
integer(int32) :: r(3)
character(len=1) :: s(3)
character(len=2) :: gas = "O2"
integer(int32) :: heavywater = 0
type(gas_type), pointer :: gases_list(:)
character(len=:), pointer :: gases_str

print *, '##### IAPWS VERSION #####'
print *, "version ", get_version()

print *, '##### IAPWS R2-83 #####'
print "(a, f10.3, a)", "Tc in h2o=", Tc_H2O, " k"
print "(a, f10.3, a)", "pc in h2o=", pc_H2O, " mpa"
print "(a, f10.3, a)", "rhoc in h2o=", rhoc_H2O, " kg/m3"

print "(a, f10.3, a)", "Tc in D2O=", Tc_D2O, " k"
print "(a, f10.3, a)", "pc in D2O=", pc_D2O, " mpa"
print "(a, f10.3, a)", "rhoc in D2O=", rhoc_D2O, " kg/m3"
print *, ''

print *, '##### IAPWS G7-04 #####'
! Compute kh and kd in H2O
T(1) = 25.0_dp + 273.15_dp
call kh(T, gas, heavywater, kh_res)
print "(A10, 1X, A10, 1X, A2, F10.1, A, 4X, A3, SP, F10.4)", "Gas=", gas,

call kd(T, gas, heavywater, kd_res)
print "(A10, 1X, A10, 1X, A2, F10.1, A, 4X, A3, SP, F15.4)", "Gas=", gas,

! Get and print available gases
heavywater = 0
ngas = ngases(heavywater)
gases_list => null()
gases_list => gases(heavywater)
gases_str => gases2(heavywater)
print *, "Gases in H2O: ", ngas
print *, gases_str
do i=1, ngas
    print *, gases_list(i)%gas
enddo

```



```

heavywater = 1
ngas = ngases(heavywater)
gases_list => null()
gases_list => gases(heavywater)
gases_str => gases2(heavywater)
print *, "Gases in D2O: ", ngas
print *, gases_str
do i=1, ngas
    print *, gases_list(i)%gas
enddo

print *, '##### IAPWS R7-97 #####'
! Compute ps from Ts.
Ts(:) = [-1.0_dp, 25.0_dp, 100.0_dp, 200.0_dp, 300.0_dp, 360.0_dp, 374.0_dp]
Ts(:) = Ts(:) + 273.15_dp
call psat(Ts, ps)

do i=1, size(Ts)
    print "(SP, F23.3, A3, 4X, F23.3, A3)", Ts(i), "K", ps(i), "MPa"
end do

! Compute Ts from ps
call Tsat(ps, Ts)
do i=1, size(Ts)
    print "(SP, F23.3, A3, 4X, F23.3, A3)", Ts(i), "K", ps(i), "MPa"
end do

! Compute water properties at 280°C/8 Mpa
p(1) = 8.0_dp
T(1) = 273.15_dp + 280.0_dp
call wp(p, T, "v", wp_res)
print "(A5, F23.16, X, A)", "v(8MPa,280°C)=", wp_res(1)*1000.0_dp, "L/kg"

! Compute region and phase
x = [8.0_dp, 4.0_dp, 6.0_dp]
y = [553.15_dp, 1200.0_dp, 2000.0_dp]
call wr(x, y, r)
call wph(x, y, s)
print *, r
print *, s

end program

```

#### Example in C

```

#include <string.h>
#include <stdio.h>
#include "iapws.h"

int main(void){
double T = 25.0 + 273.15; /* in C*/
double p; /* p in Mpa */
char *gas = "O2";
double kh, kd, wp_res;
char **gases_list;

```

```

char *gases_str;
int ngas;
int i;
int heavywater = 0;
double x[3]= {8.0, 4.0, 6.0 };
double y[3] = {553.15, 1200.0, 2000.0};
int r[3];
char s[3];

printf("%s0, "##### IAPWS VERSION #####
printf("version %s0, iapws_get_version());

printf("%s0, "##### IAPWS R2-83 #####
printf("%s %10.3f %s0, "Tc in H2O", iapws_r283_Tc_H2O, "K");
printf("%s %10.3f %s0, "pc in H2O", iapws_r283_pc_H2O, "MPa");
printf("%s %10.3f %s0, "rhoc in H2O", iapws_r283_rhoc_H2O, "kg/m3");

printf("%s %10.3f %s0, "Tc in D2O", iapws_r283_Tc_D2O, "K");
printf("%s %10.3f %s0, "pc in D2O", iapws_r283_pc_D2O, "MPa");
printf("%s %10.3f %s0, "rhoc in D2O", iapws_r283_rhoc_D2O, "kg/m3");

printf("0);

printf("%s0, "##### IAPWS G7-04 #####
/* Compute kh and kd in H2O*/
iapws_g704_kh(&T, gas, heavywater, &kh, strlen(gas), 1);
printf("Gas=%sT=%fKkh=%+10.4f0, gas, T, kh);

iapws_g704_kd(&T, gas, heavywater, &kd, strlen(gas), 1);
printf("Gas=%sT=%fKkd=%+15.4f0, gas, T, kd);

/* Get and print the available gases */
ngas = iapws_g704_ngases(heavywater);
gases_list = iapws_g704_gases(heavywater);
gases_str = iapws_g704_gases2(heavywater);
printf("Gases in H2O: %d0, ngas);
printf("%s0, gases_str);
for(i=0; i<ngas; i++){
    printf("%s0, gases_list[i]);
}

heavywater = 1;
ngas = iapws_g704_ngases(heavywater);
gases_list = iapws_g704_gases(heavywater);
gases_str = iapws_g704_gases2(heavywater);
printf("Gases in D2O: %d0, ngas);
printf("%s0, gases_str);
for(i=0; i<ngas; i++){
    printf("%s0, gases_list[i]);
}

printf("%s0, "##### IAPWS R7-97 #####
double Ts[7] = {-1.0, 25.0, 100.0, 200.0, 300.0, 360.0, 374.0};

```

```

double ps[7] = {1.0, 1.0, 1.0, 1.0, 1.0, 1.0, 1.0};
for(i=0; i<7; i++){
    Ts[i] = Ts[i] + 273.15;
}
iapws_r797_psat(7, Ts, ps);

for(i=0; i<7; i++){
    printf("%+23.3f %s %+23.3f %s0, Ts[i], "K", ps[i], "MPa");
}

iapws_r797_Tsat(7, ps, Ts);
for(i=0; i<7; i++){
    printf("%+23.3f %s %+23.3f %s0, Ts[i], "K", ps[i], "MPa");
}

T = 273.15 + 280.0;
p = 8.0;
iapws_r797_wp(&p, &T, "v", &wp_res, 1, 1);
printf("v(8MPa,280Â°C) = %+23.16f L/kg0, wp_res * 1000.0);

iapws_r797_wr(x, y, r, 3);
iapws_r797_wph(x, y, s, 3);
for(i=0; i<3; i++){
    printf("%i", r[i]);
}
printf("0);
for(i=0; i<3; i++){
    printf("%c", s[i]);
}
printf("0);

return 0;
}

```

#### Example in Python

```

import array
import numpy as np
import matplotlib.pyplot as plt
import pyiapws

print("##### IAPWS VERSION #####")
print(pyiapws.__version__)

print("##### IAPWS R2-83 #####")
print("Tc in H2O", pyiapws.Tc_H2O, "K")
print("pc in H2O", pyiapws.pc_H2O, "MPa")
print("rhoc in H2O", pyiapws.rhoc_H2O, "kg/m3")

print("Tc in D2O", pyiapws.Tc_D2O, "K")
print("pc in D2O", pyiapws.pc_D2O, "MPa")
print("rhoc in D2O", pyiapws.rhoc_D2O, "kg/m3")

print("")

```

```

print("##### IAPWS G7-04 #####")
gas = "O2"
T = array.array("d", (25.0+273.15,))

# Compute kh and kd in H2O
heavywater = False
k = pyiapws.kh(T, "O2", heavywater)
print(f"Gas={gas}T={T[0]}Kkh={k[0]:+10.4f}0)

k = pyiapws.kd(T, "O2", heavywater)
print(f"Gas={gas}T={T[0]}Kkd={k[0]:+10.4f}0)

# Get and print the available gases
heavywater = False
gases_list = pyiapws.gases(heavywater)
gases_str = pyiapws.gases2(heavywater)
ngas = pyiapws.ngases(heavywater)
print(f"Gases in H2O: {ngas}")
print(gases_str)
for gas in gases_list:
    print(gas)

heavywater = True
gases_list = pyiapws.gases(heavywater)
gases_str = pyiapws.gases2(heavywater)
ngas = pyiapws.ngases(heavywater)
print(f"Gases in D2O: {ngas}")
print(gases_str)
for gas in gases_list:
    print(gas)

style = {"marker": ".", "ls": "", "ms": 2}
T_KELVIN = 273.15
T = np.linspace(0.0, 360.0, 1000) + 273.15

solvent = {True: "D2O", False: "H2O"}

print("Generating plot for kh")
kname = "kh"
for HEAVYWATER in (False, True):
    print(solvent[HEAVYWATER])
    fig = plt.figure()
    ax = fig.add_subplot()
    ax.grid(visible=True, ls=':')
    ax.set_xlabel("T / Å°K")
    ax.set_ylabel("ln (kh/1GPa)")
    gases = pyiapws.gases(HEAVYWATER)
    for gas in gases:
        k = pyiapws.kh(T, gas, HEAVYWATER) / 1000.0
        ln_k = np.log(k)
        ax.plot(T, ln_k, label=gas, **style)
    ax.legend(ncol=3)
    fig.savefig(f"../media/g704-{kname:s}_{solvent[HEAVYWATER]}.png", dpi=

```

```

print("Generating plot for kd")
kname = "kd"
for HEAVYWATER in (False, True):
    print(solvent[HEAVYWATER])
    fig = plt.figure()
    ax = fig.add_subplot()
    ax.grid(visible=True, ls=':')
    ax.set_xlabel("T /ÅK")
    ax.set_ylabel("ln kd")
    gases = pyiapws.gases(HEAVYWATER)
    for gas in gases:
        k = pyiapws.kd(T, gas, HEAVYWATER)
        ln_k = np.log(k)
        ax.plot(T, ln_k, label=gas, **style)
    ax.legend(ncol=3)
    fig.savefig(f"../media/g704-{kname:s}_{solvent[HEAVYWATER]}.png", dpi=100)

print("##### IAPWS R7-97 #####")
Ts = np.asarray([-1.0, 25.0, 100.0, 200.0, 300.0, 360.0, 374.0])
Ts = Ts + 273.15

ps = pyiapws.psat(Ts)
for i in range(Ts.size):
    print(f"{Ts[i]:23.3f} K {ps[i]:23.3f} MPa.")

Ts = pyiapws.Tsat(ps)
for i in range(Ts.size):
    print(f"{Ts[i]:23.3f} K {ps[i]:23.3f} MPa.")

fig = plt.figure()
ax = fig.add_subplot()
ax.grid(visible=True, ls=':')
ax.set_xlabel("Ts /K")
ax.set_ylabel("ps /MPa")
Ts = np.linspace(0.0, 370.0, 500)
Ts = Ts + 273.15

ps = pyiapws.psat(Ts)
ax.plot(Ts, ps, "r-", label="ps(Ts)")

Ts = pyiapws.Tsat(ps)
ax.plot(Ts, ps, "b--", label="Ts(ps)")

ax.legend()
fig.savefig(f"../media/r797-r4.png", dpi=100, format="png")

T = 280.0 + 273.15
p = 8.0
res = pyiapws.wp(p, T, "v")*1000.0
print(f"v(8MPa,280ÅC) = {res:+23.16f} L/kg")

```

```
x = np.asarray([8.0, 4.0, 6.0 ])
y = np.asarray([553.15, 1200.0, 2000.0])
r=pyiapws.wr(x, y)
s=pyiapws.wph(x, y)
print(r)
print(s)

plt.show()
```

**SEE ALSO****codata(3), ciaaw(3)**