



Kjemisk Institutt

EKSAMEN I MNKKJ231 / SIK3031

VIDEREGÅENDE UORGANISK KJEMI I

(3 vekttall)

Torsdag 29. november 2001

kl. 0900 – 1400

Eksamensoppgaven består av tre sider.

Alle oppgaver skal besvares.

Sensurfrist 21. desember 2001

Faglærer: Professor David G. Nicholson tel.: 96204

Tillatte hjelpeemidler: B1-Typegodkjent kalkulator med tomt minner. Ingen trykte eller håndskrevne hjelpeemidler tillatt.

VIKTIG! Følgende punkter vil bli lagt til grunn under eksamsretting:

- at kandidaten uttrykker seg på en klar, strukturert og logisk måte
- besvarelse uten begrunnelse får fratrekk selvom svaret er riktig
- besvarelsene skal være lesbare.—**bruk pen og ikke blyant.**

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1. a. Kan et trigonalt plant molekyl, som f.eks. BF_3 , ha trippeldegenererte orbitaler? Begrunn svaret.
 - b. Identifisér symmetritypen for orbitalkombinasjonen

$$\psi = \phi - \phi'$$

- i et NO_2 molecule (C_{2v} symmetry), hvor ϕ er en $2p_x$ orbital på ett av O atomene og ϕ' er en $2p_x$ orbital på det andre O atomet.
- c. Molekylionet H_3^+ er blitt observert, men strukturen er omdiskutert. Gjør rede for molekylorbitaldiagrammer for dette molekylionet der det antas at strukturen er:
- en lineær struktur
 - en syklisk struktur
- d. Bruk gruppeteori til å konstruere et rent σ (dvs. ingen π -binding) MO diagram for et trigonal plant kompleks, der sentralatomet er et første rads innskuddsmetall (3d-element). Angi også hvilke d -orbitaler som er involvert i bindingene.
2. a. Skissér og beskriv energinivådiagrammer for oktaedriske innskuddsmetallkomplekser med utgangspunkt i
 - krystalfeltmodellen
 - molekylorbitalmodellen.Gjør rede for noen fundamentale forskjeller mellom disse to modellene.
- b. Skissér og beskriv energinivådiagrammer for komplekser hvor en tar hensyn til π -interaksjoner med akseptorligander (f.eks. CO).
- c. Jahn-Teller teoremet gjelder for komplekser med hvilken som helst geometri. Hvilke av d^0 - d^{10} konfigurasjoner i tetraedriske komplekser er forbundet med Jahn-Teller fordreining?
- d. Blant mononukleære karbonyler har $\text{V}(\text{CO})_6$ uvanlig tendens til å undergå ett-elektron reduksjon (one-electron reduction). Forklar dette.

3. a. Assignér punktgruppesymboler til hvert av følgende molekyler: ClF_3 , C_2H_2 , SF_5Cl , C_2H_4 , $\text{B}_3\text{N}_3\text{H}_6$ (som har benzenstruktur der C atomer erstattes av B og N vekselvis), SiCl_2Br_2 , PF_5 , BFClBr .
- b. Forklar hvorfor TeCl_4 molekylet har et dipolmoment, mens SnCl_4 molekylet ikke har det.

The groups C_1 , C_s , C_i

C_1 (1)	E	$h = 1$	$C_s = C_h$ (m)	E	σ_h	$h = 2$
A	1		A'	1	1	x, y, R_z x^2, y^2, z^2, xy
			A''	1	-1	z, R_x, R_y yz, zx

$C_1 = S_2$ (1)	E	i	$h = 2$
A _g	1	1	R_x, R_y, R_z $x^2, y^2, z^2, xy, zx, yz$
A _u	1	-1	x, y, z

The groups C_n

C_2 (2)	E	C_2	$h = 2$
A	1	1	z, R_z x^2, y^2, z^2, xy
B	1	-1	x, y, R_x, R_y yz, zx

C_3 (3)	E	C_3	C_3^2	$\varepsilon = \exp(2\pi i/3)$	$h = 3$
A	1	1	1	z, R_z	$x^2 + y^2, z^2$
E	$\begin{cases} 1 & \varepsilon & \varepsilon^2 \\ 1 & \varepsilon^* & \varepsilon \end{cases}$	$(x, y) (R_x, R_y)$	$(x^2 - y^2, xy) (yz, zx)$		

C_4 (4)	E	C_4	C_2	C_4^3	$h = 4$	
A	1	1	1	1	z, R_z $x^2 + y^2, z^2$	
B	1	-1	1	-1		$x^2 - y^2, xy$
E	$\begin{cases} 1 & i & -1 & i \\ 1 & -i & 1 & -i \end{cases}$				$(x, y) (R_x, R_y)$ (yz, zx)	

The groups C_{nv}

C_{2v} (2mm)	E	C_2	$\sigma_v(xz)$	$\sigma'_v(yz)$	$h = 4$
A ₁	1	1	1	1	z x^2, y^2, z^2
A ₂	1	1	-1	-1	R_z xy
B ₁	1	-1	1	-1	x, R_y zx
B ₂	1	-1	-1	1	y, R_x yz

C_{3v} (3m)	E	$2C_3$	$3\sigma_v$	$h = 6$
A ₁	1	1	1	z $x^2 + y^2, z^2$
A ₂	1	1	-1	R_z
E	2	-1	0	$(x, y) (R_x, R_y)$ $(x^2 - y^2, xy) (zx, yz)$

C_{4v} (4mm)	E	$2C_4$	C_2	$2\sigma_v$	$2\sigma_d$	$h = 8$
A ₁	1	1	1	1	1	z $x^2 + y^2, z^2$
A ₂	1	1	1	-1	-1	R_z
B ₁	1	-1	1	1	-1	$x^2 - y^2$
B ₂	1	-1	1	-1	1	yz
E	2	0	-2	0	0	$(x, y) (R_x, R_y) (zx, yz)$

C_{5v}	E	$2C_5$	$2C_5^2$	$5\sigma_v$	$h = 10, \alpha = 72^\circ$
A ₁	1	1	1	1	z $x^2 + y^2, z^2$
A ₂	1	1	1	-1	R_z
E ₁	2	$2 \cos x$	$2 \cos 2x$	0	$(x, y) (R_x, R_y) (zx, yz)$
E ₂	2	$2 \cos 2x$	$2 \cos x$	0	$(x^2 - y^2, xy)$

C_{6v} (6mm)	E	$2C_6$	$2C_3$	C_2	$3\sigma_v$	$3\sigma_d$	$h = 12$
A ₁	1	1	1	1	1	1	z $x^2 + y^2, z^2$
A ₂	1	1	1	1	-1	-1	R_z
B ₁	1	-1	1	-1	1	-1	
B ₂	1	-1	1	-1	-1	1	
E ₁	2	1	-1	-2	0	0	$(x, y) (R_x, R_y) (zx, yz)$
E ₂	2	-1	-1	2	0	0	$(x^2 - y^2, xy)$

$C_{\infty v}$	E	C_2	$2C_\phi$	$\infty\sigma_v$	$h = \infty$
A ₁ (Σ^+)	1	1	1	1	z $x^2 + y^2, z^2$
A ₂ (Σ^-)	1	1	1	-1	R_z
E ₁ (Π)	1	-2	$2 \cos \phi$	0	$(x, y) (R_x, R_y) (zx, yz)$
E ₂ (Δ)	2	2	$2 \cos 2\phi$	0	$(xy, x^2 - y^2)$
	:	:	:	:	:

the groups D_n

D_{22}	E	$C_2(z)$	$C_2(y)$	$C_2(x)$	$h = 4$
	1	1	1	1	x^2, y^2, z^2
	1	1	-1	-1	z, R_z xy
	1	-1	1	-1	y, R_y zx
	1	-1	-1	1	x, R_x yz

D_3 (32)	E	$2C_3$	$3C_2$	$h = 6$
A ₁	1	1	1	$x^2 + y^2, z^2$
A ₂	1	1	-1	z, R_z
E	2	-1	0	$(x, y) (R_x, R_y) (x^2 - y^2, xy) (zx, yz)$

The groups D_{nh}

D_{2h} (mmm)	E	$C_2(z)$	$C_2(y)$	$C_2(x)$	i	$\sigma(xy)$	$\sigma(xz)$	$\sigma(yz)$	$h = 8$
A_g	1	1	1	1	1	1	1	1	x^2, y^2, z^2
B_{1g}	1	1	-1	-1	1	1	-1	-1	R_z
B_{2g}	1	-1	1	-1	1	-1	1	-1	R_y
B_{3g}	1	-1	-1	1	1	-1	-1	1	R_x
A_u	1	1	1	1	-1	-1	-1	-1	
B_{1u}	1	1	-1	-1	-1	-1	1	1	z
B_{2u}	1	-1	1	-1	-1	1	-1	1	y
B_{3u}	1	-1	-1	1	-1	1	1	-1	x

D_{3h} (6m2)	E	$2C_3$	$3C_2$	σ_h	$2S_3$	$3\sigma_v$	$h = 12$
A'_1	1	1	1	1	1	1	$x^2 + y^2, z^2$
A'_2	1	1	-1	1	1	-1	R_z
E'	2	-1	0	2	-1	0	(x, y)
A''_1	1	1	1	-1	-1	-1	
A''_2	1	1	-1	-1	-1	1	z
E''	2	-1	0	-2	1	0	(R_x, R_y)
							(zx, yz)

D_{4h} (4/mmm)	E	$2C_4$	C_2	$2C'_2$	$2C''_2$	i	$2S_4$	σ_h	$2\sigma_v$	$2\sigma_d$	$h = 16$
A_{1g}	1	1	1	1	1	1	1	1	1	1	$x^2 + y^2, z^2$
A_{2g}	1	1	1	-1	-1	1	1	1	-1	-1	R_z
B_{1g}	1	-1	1	1	-1	1	-1	1	1	-1	$x^2 - y^2$
B_{2g}	1	-1	1	-1	1	1	-1	1	-1	1	xy
E_g	2	0	-2	0	0	2	0	-2	0	0	(R_x, R_y)
A_{1u}	1	1	1	1	1	-1	-1	-1	-1	-1	
A_{2u}	1	1	1	-1	-1	-1	-1	-1	1	1	z
B_{1u}	1	-1	1	1	-1	-1	1	-1	-1	1	
B_{2u}	1	-1	1	-1	1	-1	1	-1	1	-1	
E_u	2	0	-2	0	0	-2	0	2	0	0	(x, y)

The groups D_{nh} (continued)

D_{sh}	E	$2C_5$	$2C_5^2$	$5C_2$	σ_h	$2S_5$	$2S_5^3$	$5\sigma_v$	$h = 20, \alpha = 72^\circ$
A'_1	1	1	1	1	1	1	1	1	$x^2 + y^2, z^2$
A'_2	1	1	1	-1	1	1	1	-1	R_z
E'_1	2	$2 \cos \alpha$	$2 \cos 2\alpha$	0	2	$2 \cos \alpha$	$2 \cos 2\alpha$	0	(x, y)
E'_2	2	$2 \cos 2\alpha$	$2 \cos \alpha$	0	2	$2 \cos 2\alpha$	$2 \cos \alpha$	0	$(x^2 - y^2, xy)$
A''_1	1	1	1	1	-1	-1	-1	-1	
A''_2	1	1	1	-1	-1	-1	-1	1	z
E''_1	2	$2 \cos \alpha$	$2 \cos 2\alpha$	0	-2	$-2 \cos \alpha$	$-2 \cos 2\alpha$	0	(R_x, R_y)
E''_2	2	$2 \cos 2\alpha$	$2 \cos \alpha$	0	-2	$-2 \cos 2\alpha$	$-2 \cos \alpha$	0	(zx, yz)

D_{oh} (6/mmm)	E	$2C_6$	$2C_3$	C_2	$3C'_2$	$3C''_2$	i	$2S_3$	$2S_6$	σ_h	$3\sigma_d$	$3\sigma_v$	$h = 24$
A_{1g}	1	1	1	1	1	1	1	1	1	1	1	1	$x^2 + y^2, z^2$
A_{2g}	1	1	1	1	-1	-1	1	1	1	1	-1	-1	R_z
B_{1g}	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	
B_{2g}	1	-1	1	-1	-1	1	1	-1	1	-1	-1	1	
E_{1g}	2	1	-1	-2	0	0	2	1	-1	-2	0	0	(R_x, R_y)
E_{2g}	2	-1	-1	2	0	0	2	-1	-1	2	0	0	$(x^2 - y^2, xy)$
A_{1u}	1	1	1	1	1	1	-1	-1	-1	-1	-1	-1	
A_{2u}	1	1	1	1	-1	-1	-1	-1	-1	-1	1	1	z
B_{1u}	1	-1	1	-1	1	-1	-1	1	-1	1	-1	1	
B_{2u}	1	-1	1	-1	-1	1	-1	1	-1	1	1	-1	
E_{1u}	2	1	-1	-2	0	0	-2	-1	1	2	0	0	(x, y)
Σ_u	2	-1	-1	2	0	0	-2	1	1	-2	0	0	

D_{zh}	E	$2C'_{\infty}$	∞C_2	$2C_3$	i	$\infty \sigma_v$	$2S_v$	$h = \infty$
$A_{1g} (\Sigma_g^+)$	1	1	D_{sh}	E	$\infty C'_2$	$2C_3$	i	$\infty \sigma_v$
$A_{1u} (\Sigma_u^-)$	1	-1	$A_{1g} (\Sigma_g')$	1	1	1	1	1
$A_{2g} (\Sigma_g^-)$	1	-1	$A_{1u} (\Sigma_u')$	1	-1	1	-1	-1
$A_{2u} (\Sigma_u^-)$	1	1	$A_{2g} (\Sigma_g')$	1	-1	1	-1	1
$E_{1g} (\Pi_g)$	2	0	$A_{2u} (\Sigma_u')$	1	1	-1	-1	-1
$E_{1u} (\Pi_u)$	2	0	$E_{1g} (\Pi_g)$	2	0	$2 \cos \phi$	2	0
$E_{2g} (\Delta_g)$	2	0	$E_{1u} (\Pi_u)$	2	0	$2 \cos \phi$	-2	0
$E_{2u} (\Delta_u)$	2	0	$E_{2g} (\Delta_g)$	2	0	$2 \cos 2\phi$	2	0
			$E_{2u} (\Delta_u)$	2	0	$2 \cos 2\phi$	-2	0

The groups D_{nd}

$D_{2d} = V_d$ (42m)	E	$2S_4$	C_2	$2C'_2$	$2\sigma_d$	$h = 8$	D_{3d} (3m)	E	$2C_3$	$3C_2$	i	$2S_6$	$3\sigma_d$	$h = 12$
A_1	1	1	1	1	1	$x^2 + y^2, z^2$	A_{1g}	1	1	1	1	1	1	$x^2 + y^2, z^2$
A_2	1	1	1	-1	-1	R_z	A_{2g}	1	1	-1	1	1	-1	R_z
B_1	1	-1	1	1	-1	$x^2 - y^2$	E_g	2	-1	0	2	-1	0	(R_x, R_y) $(x^2 - y^2, xy)$ (zx, yz)
B_2	1	-1	1	-1	1	xy	A_{1u}	1	1	1	-1	-1	-1	
E	2	0	-2	0	0	(x, y) (R_x, R_y)	A_{2u}	1	1	-1	-1	-1	1	z
							E_u	2	-1	0	-2	1	0	(x, y)

D_{4d}	E	$2S_8$	$2C_4$	$2S_8^3$	C_2	$4C'_2$	$4\sigma_d$	$h = 16$
A ₁	1	1	1	1	1	1	1	$x^2 + y^2, z^2$
A ₂	1	1	1	1	1	-1	-1	R_z
B ₁	1	-1	1	-1	1	1	-1	
B ₂	1	-1	1	-1	1	-1	1	z
E ₁	2	$\sqrt{2}$	0	$-\sqrt{2}$	-2	0	0	(x, y)
E ₂	2	0	-2	0	2	0	0	$(x^2 - y^2, xy)$
E ₃	2	$-\sqrt{2}$	0	$\sqrt{2}$	-2	0	0	(R_x, R_y) (zx, yz)

The cubic groups

T_d (43m)	E	$8C_3$	$3C_2$	$6S_4$	$6\sigma_d$	$h = 24$
A_1	1	1	1	1	1	$x^2 + y^2 + z^2$
A_2	1	1	1	-1	-1	
E	2	-1	2	0	0	$\begin{aligned} & (2z^2 - x^2 - y^2 \\ & x^2 - y^2) \end{aligned}$
T_1	3	0	-1	1	-1	(R_x, R_y, R_z)
T_2	3	0	-1	-1	1	(x, y, z)
						(xy, yz, zx)

The cubic groups (continued)

O_h (m3m)	E	$8C_3$	$6C_2$	$6C_4$	$3C_2$ (= C_4^2)	i	$6S_4$	$8S_6$	$3\sigma_h$	$6\sigma_d$	$h = 48$
A_{1g}	1	1	1	1	1	1	1	1	1	1	$x^2 + y^2 + z^2$
A_{2g}	1	-1	-1	-1	1	1	-1	1	1	-1	
E_g	2	-1	0	0	2	2	0	-1	2	0	$(2z^2 - x^2 - y^2,$ $x^2 - y^2)$
T_{1g}	3	0	-1	1	-1	3	1	0	-1	-1	$(R_x, R_y R_z)$
T_{2g}	3	0	1	-1	-1	3	-1	0	-1	1	(xy, yz, zx)
A_{1u}	1	1	1	1	1	-1	-1	-1	-1	-1	
A_{2u}	1	1	-1	-1	1	-1	1	-1	-1	1	
E_u	2	-1	0	0	2	-2	0	1	-2	0	
T_{1u}	3	0	-1	1	-1	-3	-1	0	1	1	(x, y, z)
T_{2u}	3	0	1	-1	-1	-3	1	0	1	-1	

The icosahedral group

I	E	$12C_5$	$12C_5^2$	$20C_3$	$15C_2$	$h = 60$
A_1	1	1	1	1	1	$x^2 + y^2 + z^2$
T_1	3	$\frac{1}{2}(1 + \sqrt{5})$	$\frac{1}{2}(1 + \sqrt{5})$	0	-1	(x, y, z)
						(R_x, R_y, R_z)
T_2	3	$\frac{1}{2}(1 + \sqrt{5})$	$\frac{1}{2}(1 + \sqrt{5})$	0	-1	
G	4	-1	-1	1	0	
H	5	0	0	-1	1	$(2z^2 - x^2 - y^2,$ $x^2 - y^2, xy, yz, zx)$

Further information: P.W. Atkins, M.S. Child, and C.S.G. Phillips, *Tables for group theory*. Oxford University Press (1970).

The groups C_1 , C_s , C_i

C_1 (1)	E	$h = 1$	$C_s = C_h$ (m)	E	σ_h	$h = 2$	$C_i = S_2$ (I)	E	i	$h = 2$		
A	1		A'	1	1	x, y, R_z	x^2, y^2, z^2, xy	A _g	1	1	R_x, R_y, R_z	$x^2, y^2, z^2, xy, zx, yz$
			A''	1	-1	z, R_x, R_y	yz, zx	A _u	1	-1	x, y, z	

The groups C_n

C_2 (2)	E	C_2	$h = 2$		
A	1	1	z, R_z		x^2, y^2, z^2, xy
B	1	-1	x, y, R_x, R_y		yz, zx

C_3 (3)	E	C_3	C_3^2	$\varepsilon = \exp(2\pi i/3)$	$h = 3$
A	1	1	1	z, R_z	$x^2 + y^2, z^2$
E	$\begin{cases} 1 & \varepsilon & \varepsilon^2 \\ 1 & \varepsilon^* & \varepsilon \end{cases}$			$(x, y) (R_x, R_y)$	$(x^2 - y^2, xy) (yz, zx)$

C_4 (4)	E	C_4	C_2	C_4^3	$h = 4$		
A	1	1	1	1	z, R_z		$x^2 + y^2, z^2$
B	1	-1	1	-1			$x^2 - y^2, xy$
E	$\begin{cases} 1 & i & -1 & i \\ 1 & -i & 1 & -i \end{cases}$				$(x, y) (R_x, R_y)$	(yz, zx)	

The groups C_{nv}

C_{2v} (2mm)	E	C_2	$\sigma_v(xz)$	$\sigma'_v(yz)$	$h = 4$		
A ₁	1	1	1	1	z	x^2, y^2, z^2	
A ₂	1	1	-1	-1	R_z	xy	
B ₁	1	-1	1	-1	x, R_y	zx	
B ₂	1	-1	-1	1	y, R_x	yz	

C_{3v} (3m)	E	$2C_3$	$3\sigma_v$	$h = 6$		
A ₁	1	1	1	z		$x^2 + y^2, z^2$
A ₂	1	1	-1	R_z		
E	2	-1	0	$(x, y) (R_x, R_y)$	$(x^2 - y^2, xy) (yz, zx)$	

C_{4v} (4mm)	E	$2C_4$	C_2	$2\sigma_v$	$2\sigma_d$	$h = 8$
A ₁	1	1	1	1	1	z $x^2 + y^2, z^2$
A ₂	1	1	1	-1	-1	R_z
B ₁	1	-1	1	1	-1	$x^2 - y^2$
B ₂	1	-1	1	-1	1	yz
E	2	0	-2	0	0	$(x, y) (R_x, R_y) (zx, yz)$

C_{5v}	E	$2C_5$	$2C_5^2$	$5\sigma_v$	$h = 10, \alpha = 72^\circ$
A ₁	1	1	1	1	z $x^2 + y^2, z^2$
A ₂	1	1	1	-1	R_z
E ₁	2	$2 \cos z$	$2 \cos 2z$	0	$(x, y) (R_x, R_y) (zx, yz)$
E ₂	2	$2 \cos 2z$	$2 \cos z$	0	$(x^2 - y^2, xy)$

C_{6v} (6mm)	E	$2C_6$	$2C_3$	C_2	$3\sigma_v$	$3\sigma_d$	$h = 12$
A ₁	1	1	1	1	1	1	z $x^2 + y^2, z^2$
A ₂	1	1	1	1	-1	-1	R_z
B ₁	1	-1	1	-1	1	-1	
B ₂	1	-1	1	-1	-1	1	
E ₁	2	1	-1	-2	0	0	$(x, y) (R_x, R_y) (zx, yz)$
E ₂	2	-1	-1	2	0	0	$(x^2 - y^2, xy)$

$C_{\infty v}$	E	C_2	$2C_\phi$	$\infty\sigma_v$	$h = \infty$
A ₁ (Σ^+)	1	1	1	1	z $x^2 + y^2, z^2$
A ₂ (Σ^-)	1	1	1	-1	R_z
E ₁ (Π)	1	-2	$2 \cos \phi$	0	$(x, y) (R_x, R_y) (zx, yz)$
E ₂ (Δ)	2	2	$2 \cos 2\phi$	0	$(xy, x^2 - y^2)$
\vdots	\vdots	\vdots	\vdots	\vdots	\vdots

he groups D_n

D_{22}	E	$C_2(z)$	$C_2(y)$	$C_2(x)$	$h = 4$
	1	1	1	1	x^2, y^2, z^2
	1	1	-1	-1	z, R_z xy
	1	-1	1	-1	y, R_y zx
	1	-1	-1	1	x, R_x yz

D_3 (32)	E	$2C_3$	$3C_2$	$h = 6$
A ₁	1	1	1	$x^2 + y^2, z^2$
A ₂	1	1	-1	z, R_z
E	2	-1	0	$(x, y) (R_x, R_y)$ $(x^2 - y^2, xy) (zx, yz)$

The groups D_{nh}

D_{2h} (mmm)	E	$C_2(z)$	$C_2(y)$	$C_2(x)$	i	$\sigma(xy)$	$\sigma(xz)$	$\sigma(yz)$	$h = 8$
A_g	1	1	1	1	1	1	1	1	x^2, y^2, z^2
B_{1g}	1	1	-1	-1	1	1	-1	-1	R_z
B_{2g}	1	-1	1	-1	1	-1	1	-1	R_y
B_{3g}	1	-1	-1	1	1	-1	-1	1	R_x
A_u	1	1	1	1	-1	-1	-1	-1	
B_{1u}	1	1	-1	-1	-1	-1	1	1	z
B_{2u}	1	-1	1	-1	-1	1	-1	1	y
B_{3u}	1	-1	-1	1	-1	1	1	-1	x

D_{3h} (6m2)	E	$2C_3$	$3C_2$	σ_h	$2S_3$	$3\sigma_v$	$h = 12$
A'_1	1	1	1	1	1	1	$x^2 + y^2, z^2$
A'_2	1	1	-1	1	1	-1	R_z
E'	2	-1	0	2	-1	0	(x, y)
A''_1	1	1	1	-1	-1	-1	
A''_2	1	1	-1	-1	-1	1	z
E''	2	-1	0	-2	1	0	(R_x, R_y)
							(zx, yz)

D_{4h} (4/mmm)	E	$2C_4$	C_2	$2C'_2$	$2C''_2$	i	$2S_4$	σ_h	$2\sigma_v$	$2\sigma_d$	$h = 16$
A_{1g}	1	1	1	1	1	1	1	1	1	1	$x^2 + y^2, z^2$
A_{2g}	1	1	1	-1	-1	1	1	1	-1	-1	R_z
B_{1g}	1	-1	1	1	-1	1	-1	1	1	-1	$x^2 - y^2$
B_{2g}	1	-1	1	-1	1	1	-1	1	-1	1	xy
E_g	2	0	-2	0	0	2	0	-2	0	0	(R_x, R_y)
A_{1u}	1	1	1	1	1	-1	-1	-1	-1	-1	
A_{2u}	1	1	1	-1	-1	-1	-1	-1	1	1	z
B_{1u}	1	-1	1	1	-1	-1	1	-1	-1	1	
B_{2u}	1	-1	1	-1	1	-1	1	-1	1	-1	
E_u	2	0	-2	0	0	-2	0	2	0	0	(x, y)

The groups D_{nh} (continued)

D_{sh}	E	$2C_5$	$2C_5^2$	$5C_2$	σ_h	$2S_5$	$2S_5^3$	$5\sigma_v$	$h = 20, \alpha = 72^\circ$
A'_1	1	1	1	1	1	1	1	1	$x^2 + y^2, z^2$
A'_2	1	1	1	-1	1	1	1	-1	R_z
E'_1	2	$2 \cos \alpha$	$2 \cos 2\alpha$	0	2	$2 \cos \alpha$	$2 \cos 2\alpha$	0	(x, y)
E'_2	2	$2 \cos 2\alpha$	$2 \cos \alpha$	0	2	$2 \cos 2\alpha$	$2 \cos \alpha$	0	$(x^2 - y^2, xy)$
A''_1	1	1	1	1	-1	-1	-1	-1	
A''_2	1	1	1	-1	-1	-1	-1	1	z
E''_1	2	$2 \cos \alpha$	$2 \cos 2\alpha$	0	-2	$-2 \cos \alpha$	$-2 \cos 2\alpha$	0	(R_x, R_y)
E''_2	2	$2 \cos 2\alpha$	$2 \cos \alpha$	0	-2	$-2 \cos 2\alpha$	$-2 \cos \alpha$	0	(zx, yz)

D_{6h} (6/mmm)	E	$2C_6$	$2C_3$	C_2	$3C'_2$	$3C''_2$	i	$2S_3$	$2S_6$	σ_h	$3\sigma_d$	$3\sigma_v$		$h = 24$
A_{1g}	1	1	1	1	1	1	1	1	1	1	1	1		$x^2 + y^2, z^2$
A_{2g}	1	1	1	-1	-1	-1	1	1	1	1	-1	-1	R_z	
B_{1g}	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1		
B_{2g}	1	-1	1	-1	-1	1	1	-1	1	-1	-1	1		
E_{1g}	2	1	-1	-2	0	0	2	1	-1	-2	0	0	(R_x, R_y)	(zx, yz)
E_{2g}	2	-1	-1	2	0	0	2	-1	-1	2	0	0		$(x^2 - y^2, xy)$
A_{1u}	1	1	1	1	1	1	-1	-1	-1	-1	-1	-1		
A_{2u}	1	1	1	1	-1	-1	-1	-1	-1	-1	1	1	z	
B_{1u}	1	-1	1	-1	1	-1	-1	1	-1	1	-1	1		
B_{2u}	1	-1	1	-1	-1	1	-1	1	-1	1	1	-1		
E_{1u}	2	1	-1	-2	0	0	-2	-1	1	2	0	0	(x, y)	
e_u	2	-1	-1	2	0	0	-2	1	1	-2	0	0		

The groups D_{nd}

$D_{2d} = V_d$ ($\bar{4}2m$)	E	$2S_4$	C_2	$2C'_2$	$2\sigma_d$	$h = 8$	D_{3d} ($\bar{3}m$)	E	$2C_3$	$3C_2$	i	$2S_6$	$3\sigma_d$	$h = 12$
A_1	1	1	1	1	1	$x^2 + y^2, z^2$	A_{1g}	1	1	1	1	1	1	$x^2 + y^2, z^2$
A_2	1	1	1	-1	-1	R_z	A_{2g}	1	1	-1	1	1	-1	R_z
B_1	1	-1	1	1	-1	$x^2 - y^2$	E_g	2	-1	0	2	-1	0	(R_x, R_y) $(x^2 - y^2, xy)$ (zx, yz)
B_2	1	-1	1	-1	1	xy	A_{1u}	1	1	1	-1	-1	-1	
E	2	0	-2	0	0	(x, y) (R_x, R_y)	A_{2u}	1	1	-1	-1	-1	1	z
							E_u	2	-1	0	-2	1	0	(x, y)

D_{4d}	E	$2S_8$	$2C_4$	$2S_8^8$	C_2	$4C'_2$	$4\sigma_d$	$h = 16$
A_1	1	1	1	1	1	1	1	$x^2 + y^2, z^2$
A_2	1	1	1	1	1	-1	-1	R_z
B_1	1	-1	1	-1	1	1	-1	
B_2	1	-1	1	-1	1	-1	1	z
E_1	2	$\sqrt{2}$	0	$-\sqrt{2}$	-2	0	0	(x, y)
E_2	2	0	-2	0	2	0	0	$(x^2 - y^2, xy)$
E_3	2	$-\sqrt{2}$	0	$\sqrt{2}$	-2	0	0	(R_x, R_y) (zx, yz)

The cubic groups

T_d ($\bar{4}3m$)	E	$8C_3$	$3C_2$	$6S_4$	$6\sigma_d$	$h = 24$
A_1	1	1	1	1	1	$x^2 + y^2 + z^2$
A_2	1	1	1	-1	-1	
E	2	-1	2	0	0	$(2z^2 - x^2 - y^2,$ $x^2 - y^2)$
T_1	3	0	-1	1	-1	(R_x, R_y, R_z)
T_2	3	0	-1	-1	1	(x, y, z) (xy, yz, zx)

The cubic groups (continued)

O_h ($m\bar{3}m$)	E	$8C_3$	$6C_2$	$6C_4$	$3C_2$ (= C_4^2)	i	$6S_4$	$8S_6$	$3\sigma_h$	$6\sigma_d$	$h = 48$
A_{1g}	1	1	1	1	1	1	1	1	1	1	$x^2 + y^2 + z^2$
A_{2g}	1	-1	-1	-1	1	1	-1	1	1	-1	
E_g	2	-1	0	0	2	2	0	-1	2	0	$(2z^2 - x^2 - y^2, x^2 - y^2)$
T_{1g}	3	0	-1	1	-1	3	1	0	-1	-1	(R_x, R_y, R_z)
T_{2g}	3	0	1	-1	-1	3	-1	0	-1	1	(xy, yz, zx)
A_{1u}	1	1	1	1	1	-1	-1	-1	-1	-1	
A_{2u}	1	1	-1	-1	1	-1	1	-1	-1	1	
E_u	2	-1	0	0	2	-2	0	1	-2	0	
T_{1u}	3	0	-1	1	-1	-3	-1	0	1	1	(x, y, z)
T_{2u}	3	0	1	-1	-1	-3	1	0	1	-1	

The icosahedral group

I	E	$12C_5$	$12C_5^2$	$20C_3$	$15C_2$	$h = 60$
A_1	1	1	1	1	1	$x^2 + y^2 + z^2$
T_1	3	$\frac{1}{2}(1 + \sqrt{5})$	$\frac{1}{2}(1 + \sqrt{5})$	0	-1	(x, y, z)
						(R_x, R_y, R_z)
T_2	3	$\frac{1}{2}(1 + \sqrt{5})$	$\frac{1}{2}(1 + \sqrt{5})$	0	-1	
G	4	-1	-1	1	0	
H	5	0	0	-1	1	$(2z^2 - x^2 - y^2, x^2 - y^2, xy, yz, zx)$

Further information: P.W. Atkins, M.S. Child, and C.S.G. Phillips, *Tables for group theory*. Oxford University Press (1970).