5. LOODUSSEADUSTE ANALÜÜS

Cartwright:

Loodusseadused kirjeldavad, kuidas füüsikalised süsteemid käituvad

fenomenoloogilised	teoreetilised
käsitlevad ilminguid	käsitlevad reaalsust
vaadeldavad-mõõdetavad (observable)	kaudne mõju
– K I R J E L D U S	– S E L E T U S

Enc. Dict. of Physics:

Fenomenoloogiline teooria seob vaadeldud nähtusi postuleerides teatud võrrandid, tungimata nende olemusse.

Avastamine (Holton)

Enamus loodusseadusi on avastatud juhuslikult
vaja on läinud:

– intuitsiooni
– teravat mõistust
– tugevat reaalsuse taju
– sügavat usku vaatlusesse ja eksperimenti
– äratundmise oskust, eriti katse ja vaatluse ootamatu tulemuse puhul

Figure 2 Einstein on the verge of discovering his famous formula $E = mc^2$—a cartoonist's view [Har 77]. (© 1991 by Sidney Harris)

Ceteris paribus kui teised tingimused täidetud

Gravitatsiooniseadus

$$F = \frac{Gm_1m_2}{r^2}$$

Coulombi seadus (laenguga kehad)

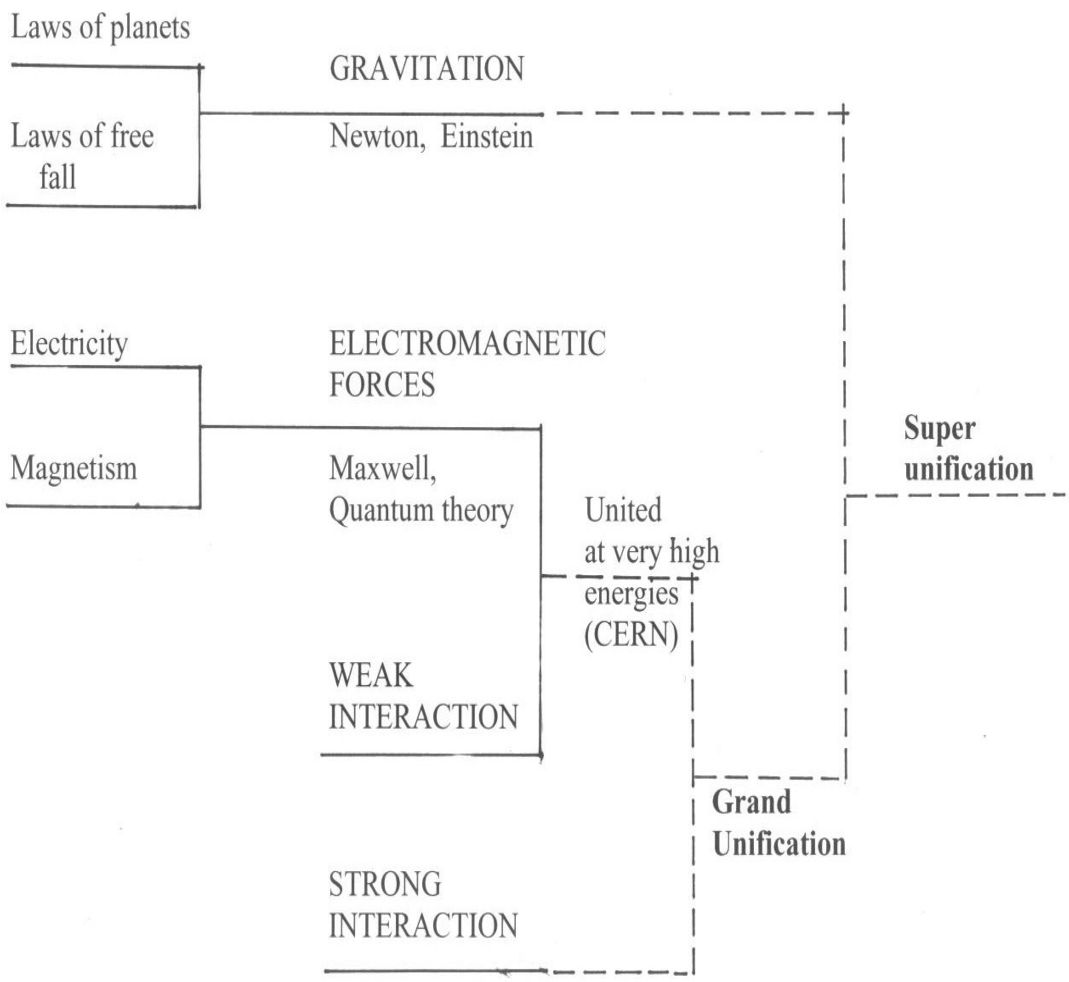
$$F = \frac{q_1q_2}{r^2}$$

Kuidas loodus neid liidab? Kas loodus teab vektorite liitmise eeskirju?

Kaks keha mõjutavad teineteist jõuga, mis on võrdeline nende masside korrutisega ja pöördvõrdeline nendevahelise kauguse ruuduga

Kui kaks keha mõjutavad teineteist ainult gravitatsioonijõuga, siis see jõud on võrdeline …

NB! Tükeldamise efekt vt loeng 2 Toffler


Laws of planets
Laws of free fall
GRAVITATION
Newton, Einstein
Electricity
Magnetism
ELECTROMAGNETIC FORCES
Maxwell, Quantum theory
United at very high energies (CERN)
WEAK INTERACTION
STRONG INTERACTION
Grand Unification
Super unification

Hooke'i seadus R. Hooke 1635 – 1703

$$\sigma = E\varepsilon$$

σ - pinge

ε - deformatsioon

E - elastsusmoodul

Ohm'i seadus G.S. Ohm 1789 – 1854

$$RI = U$$

R – takistus

I – voolutugevus

U – pinge

Fourier' seadus J. Fourier 1768 – 1830

$$q = -\lambda \frac{\partial T}{\partial x}$$

q – soojusvoog

T – temperatuuri gradient

λ – soojusjuhtivuse tegur

Boyle – Mariotte' seadus R. Boyle 1627 – 1691
E. Mariotte 1620 – 1684

$$p(t) = m\,\rho(t)$$

$p(t)$ – rõhk

$\rho(t)$ – tihedus

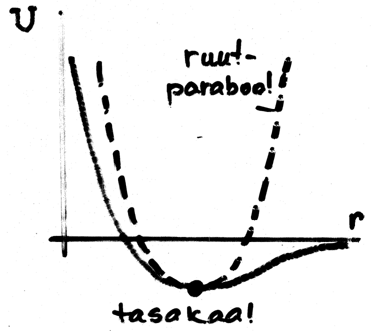
m – const

Hooke'i seadus

$\sigma = E\varepsilon$ – üldvalem 1D

Pideva keskkonna mehaanika:

$$\sigma_{KL} = \rho_0 \frac{\partial F}{\partial E_{KL}}$$



σ_{KL} – pingetensori komponendid

E_{KL} – deformatsioonitensori komponendid

ρ_0 – tihedus

F – Helmholtzi vaba energia

$$F = U - TS$$

U- siseenergia T- temp. S - entroopia

Seega: lineaarne seadus on vaid fiktsioon!

$$\sigma_{11} = (\lambda + 2\mu)\, U_{1,1} + \left(\frac{1}{2}\lambda + \mu + 3\nu_1 + 3\nu_2 + 3\upsilon_3\right) U_{1,1}{}^2 + \dots$$

$$\varepsilon = U_{1,1}$$

$$\sigma_{11} = (\lambda + 2\mu)\, U_{1,1} \quad \rightarrow \quad \sigma = E\varepsilon$$

Vt. tabel

Table 25. MEHMKE (1897).

1. *Linear law:*	$\varepsilon = a\sigma$	HOOKE (1678)
2. *Exponential law:*	$\varepsilon = a\sigma^m$	JAMES BERNOULLI (1694)[a]; BÜLFFINGER (172 tension; HODGKINSON (1822); BACH-SCHÜLE (1897)
3. *Parabolic law:*	$\sigma = a\,\varepsilon - b\,\varepsilon^2$	HODGKINSON (1849), cast iron; HARTIG (1893), cast iron, cement, cement plastc GERSTNER (1824)[b], iron piano wire
4. *Hyperbolic law:*		
	A. $\varepsilon = \dfrac{\sigma}{a - b\sigma}$	COX (1850), cast iron; LANG (1896), cast iron, stones, plaster
	B. $\varepsilon^2 = a\sigma^2 + b\sigma$	WERTHEIM (1847), organic tissues
5. *Cubic and biquadric-parabolic law:*		
	A. $\sigma = a\varepsilon + b\,\varepsilon^2 + c\,\varepsilon^3$	COX (1850), cast iron
	$\varepsilon = a\sigma + \beta\sigma^2 + \gamma\sigma^3$	J. O. THOMPSON (1891), metals, tension
	B. $\sigma = a\,\varepsilon + b\,\varepsilon^2 + c\,\varepsilon^3 + d\,\varepsilon^4$	HODGKINSON (1849), cast iron
6. *Exponential law:*		
	A. $\sigma = c\,e^{-1/\varepsilon}$	RICCATI (1731)
	B. $\varepsilon = e^{m\sigma} - 1$	IMBERT (1880), India rubber
	C. $\sigma = c\,(e^{m\varepsilon} - 1)$	HARTIG (1893), leather, tension; burned red clay, compression
	D. $\varepsilon = \sigma(a + b\,e^{m\sigma})$	PONCELET (1839), brass, tension
	E. $\sigma = \dfrac{\varepsilon}{1-\varepsilon} \cdot e^{m\varepsilon}$	HARTIG (1893), cork, compression

British Royal Iron Committee, 1849:

„henceforth Hooke's linear law of elasticity for iron in tension, compression, and flexure should be replaced by $\sigma = A\varepsilon - B\varepsilon^2$"

Fourier' seadus

$$q = -\lambda \frac{\partial T}{\partial x}$$

soojusjuhtivuse võrrand

$$\rho\, c_v \frac{\partial T}{\partial t} = \lambda \frac{\partial^2 T}{\partial x^2}$$

ρ – tihedus

c_v – erisoojus

paraboolne, st lõpmatu kiirus!

modifitseeritud Fourier' seadus

$$q = -\lambda \frac{\partial T}{\partial x} - \tau \frac{\partial q}{\partial t}$$

τ – relaksatsiooniaeg

soojusjuhtivuse võrrand

$$\rho c_v \frac{\partial T}{\partial t} + \rho c_v \tau \frac{\partial^2 T}{\partial t^2} = \lambda \frac{\partial^2 T}{\partial x^2}$$

hüperboolne – lõplik kiirus?

$$v^2 = \frac{\lambda}{\rho\, c_v \tau}, \qquad \tau - ?$$

foononmehhanism – dielektrikud

$$\tau = \frac{3\lambda}{V^2 \rho c_v}$$

foononi kiirus

elektronmehhanism – metallid

τ - ? $\sim 10^{-12}$

vaja – temperatuuri löök

kõrged sagedused.

Ilya Prigogine: Science, July/August, 1997

1) **Isaac Newton** individuaalsed osakesed

aeg – sümmeetriline

eksisteerib hõõrdumine

2) **Boltzmann** termodünaamika seadused

entroopia, termodünaamika 2. seadus

pööratav aeg → pöördumatu aeg

matemaatiliselt?

Üldine arusaam:

aeg on sümmeetriline primaarne

termodünaamika sekundaarne

3) **Max Planck**, Fr. Wilhelm Ostwald

termodünaamika primaarne

4) **H. Poincare'**

Võib-olla gaaside kineetiline teooria on sobiv mudel. Füüsikalised seadused võtavad siis täiesti uue kuju, arvatavasti on neil siis statistiline iseloom.

5) **Ilya Prigogine**

stabiilsed süsteemid $\longrightarrow$ Newtoni– tüüpi trajektoorid ja vektorid

mittestabiilsed süsteemid $\longrightarrow$ funktsioonid, kus pole vektoritega seotud

Planck + Ostwald:

termodünaamika	<u>primaarne</u>
Newtoni mehaanika	<u>sekundaarne</u>

Prigogine

tiheduse maatriks
mittestabiilsed süsteemid
tihe seos kaose teooriaga

vajalik matemaatiline kirjeldus

Vt. Jean Bricmont "Kaoseteadus või kaos teaduses?"
Akadeemia 1998, N 11, N 12;
1999, N 1.

Jüri Engelbrecht "Teaduses on kord ja vaidlused korrast"
Akadeemia 1999, N 1.

Lisa

Table 1
Level of discipline, ontology, epistemology and methodology

Discipline:	Ontology	Epistemology	Methodology
Typical question:	How is the world?	What do we know about the world?	How can we attain such knowledge?
characteristic concepts (theses):			
Heisenberg's uncertainty relations ("$\Delta \chi \cdot \Delta \rho \geq h/4\pi$")	Electrons don't have simultaneously precise position and momentum.	Position and momentum of an electron cannot both be measured or known exactly	Don't try to measure the exact position and momentum of an electron simultaneously!
Causal relations ("A is causally connected with B.")	A is the (a) cause of B. (A causes, effects, triggers, produces B. B necessarily succeeds A.)	A is the antecedent of an adequate causal explanation of B.	Try to explain B by A! Prefer deductive-nonmological (D-N) explanations!
Causal principle ("Every event has a cause.")	To every event B, there is an event A (cause) whose necessary consequence (effect) B is.	For every event, there is an adequate causal explanation.	Look incessantly for causes and for causal explanations (especially if something unexpected happens)!
Emergence ("The whole is more than the sum of its parts.")	Systems may have properties not owned by their parts.	Systemic (that is, emergent) properties cannot be explained from the knowledge of their parts.	Don't try to explain systems from their constituents!
Reducibility of biology to physics ("strong reduction")	Living systems originated from non-living systems by causal laws.	The concepts of biology can be defined by physical concepts; its laws can be derived from physical laws.	Try to explain the origin of life and the properties of organisms by physico-chemical laws! Try to synthesize organisms from abiotic substances!
Unity of science (cf. section 5)	Unity of the world (ontological unity)	Unity of scientific knowledge (epistemological unity)	Unity of scientific method (methodological Unity)

Table 2:
The fertilizing effect of the ideas of development and evolution.

Stage	Statics	Kinematics	Mechanics
Questions	"What is there? How is it?"	"How does it change in time?"	"Why is it stable? Why does it change?"
Objects	States	Processes	Forces, factors
Analysis	Structural, morphological	Temporal, genetical	Causal
Mechanics (terrestrial)	law of the lever (Archimedes, 250 B.C.)	law of free fall (Galileo, A.D. 1590)	gravitation (Newton, A.D. 1666)
Planetary motion (celestial mechanics)	heliocentrism (Aristarchos, 200 B.C., Copernicus, A.D. 1530)	elliptical orbits (Kepler, 1609)	law of gravitation, equation of motion (Newton, 1666)
Planetary system	structure (Newton, 1687)	development (Kant, 1755, Laplace, 1800)	vortex theory (von Weizsäcker, 1944)
Continents	geography (Eratosthenes, 200 B.C.)	continental drift (Wegener, 1912)	plate tectonics (Dietz, Hess 1962)
Biology	taxonomy (Linnaeus, 1740)	phylogeny (Buffon, 1760)	theory of evolution (Darwin, 1859)
Psychology	empirical psychology (Wundt, 1879)	developmental psychology (Binet, 1905)	genetic psychology (Piaget, 1950)
Linguistics	grammar (Port-Royal, 1650)	phonetic change (Grimm, 1822)	substrate theory (Ascoli, 1886—controversial)
Philosophy of science	structure of theories (Duhem, 1905)	history of science, change of theories (Popper, 1934, Kuhn, 1962)	theory dynamics (controversial)

ARISTOTLE (384 – 322 B.C.)

Causality:

1) causa materialis

2) causa formalis

3) causa efficiens

4) causa finalis

Why does a plant grow?

1) because its material components make growth possible;

2) because its physiological functions determine growth;

3) because external circumstances (nutrients in the earth, water, sunlight, etc.) impel growth;

4) because it is meant to ripen out into the perfect form.

ANAXIMENES (< 525 B.C.):

Air (αερα)

And rarefied, it became fire; condensed, wind; then cloud; further, by still stronger condensation, water; then earth; then stones; but everything else originated by these.
Eternal motion is the origin of transformation. What contracts and condenses matter, is cold; by contrast, what thins and slackens is warm.

EMPEDOCLES (492 – 430 B.C.)

Four elements: fire, water, air, earth.

"There is only one thing: mixture and exchange of what is mixed."

ANAXAGORAS (499 – 426 B.C.)

Instead of four elements:
- **unlimited number of substances that were composed of seed particles.**

PLATO (428 – 348 B.C.)

Interpreted four elements with geometric building blocks: tetrahedra, octahedra, icosahedra, cubes, dodecahedra.

(First mathematical model!)

MATEMAATILISE MODELLEERIMISE OSA?

FÜÜSIKA:

Miks mõned elementaarosakesed omavad massi, mõned aga mitte?

KEEMIA:

Millised olid keemilised reaktsioonid, mis tekitasid elu (st replikatsiooni)?

BIOLOOGIA:

Milline on proteoomi struktuur ja funktsioon?

GEOLOOGIA:

Kas pika-ajaline usaldusväärne ilmaennustus on võimalik?

ASTRONOOMIA:

Miks universum paisub ikka kiiremini?

Näide 1. Ämblikuvõrk

”mitmekihiline” niit : kaitsekiht–nahk–tuum

materjal : proteiinil põhinevad aminohapped

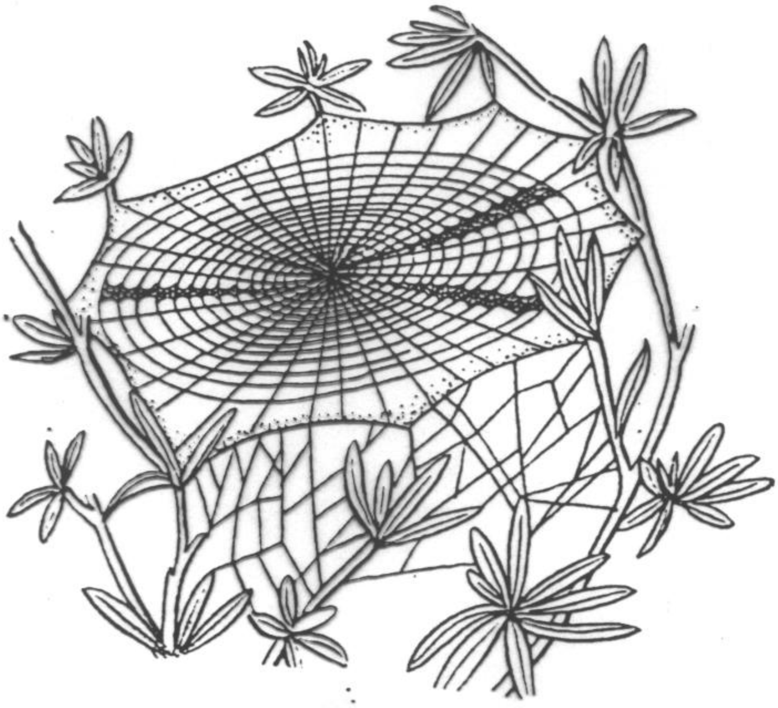
valmistamine : madal temperatuur
madal energiakulu

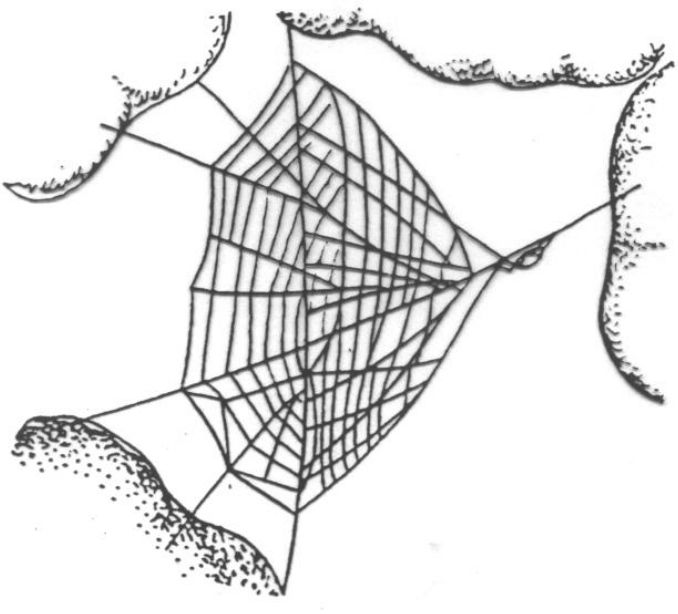
tugevusomadused : vt andmed

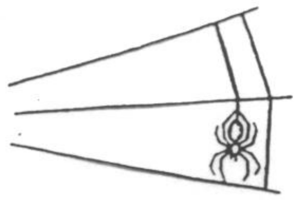
Viited :
Ämblikuvõrk

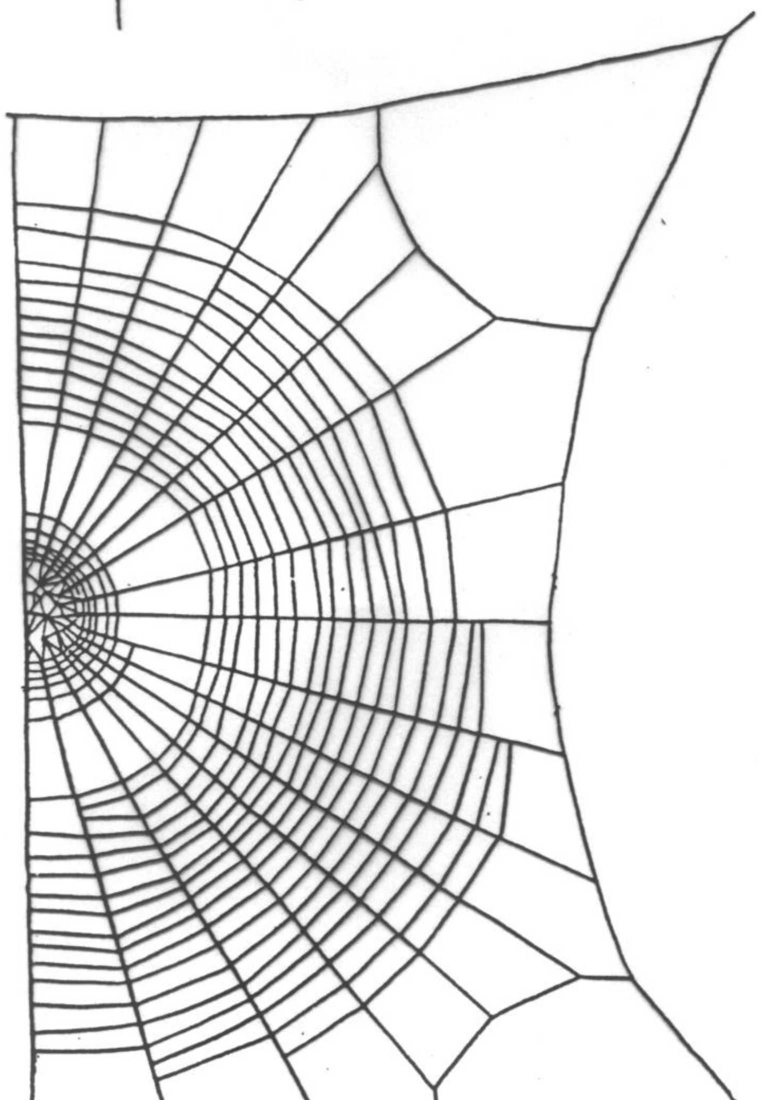
- Vollrath F. and Knight D.P. Liquid crystalline spinning of spider silk, Nature, 2001, 410, 541-548
- Engelbrecht J. Challenges for tensile stresses, Proc. Estonian Acad. Sci. Engineering, 2002, 8, No2, 134-142

Arvutus
Kulbach V. Investigation of prestressed cable structures at Tallinn Technical University, Proc. Estonian Acad. Sci. Engineering, 2002, 8, No2, 68-83





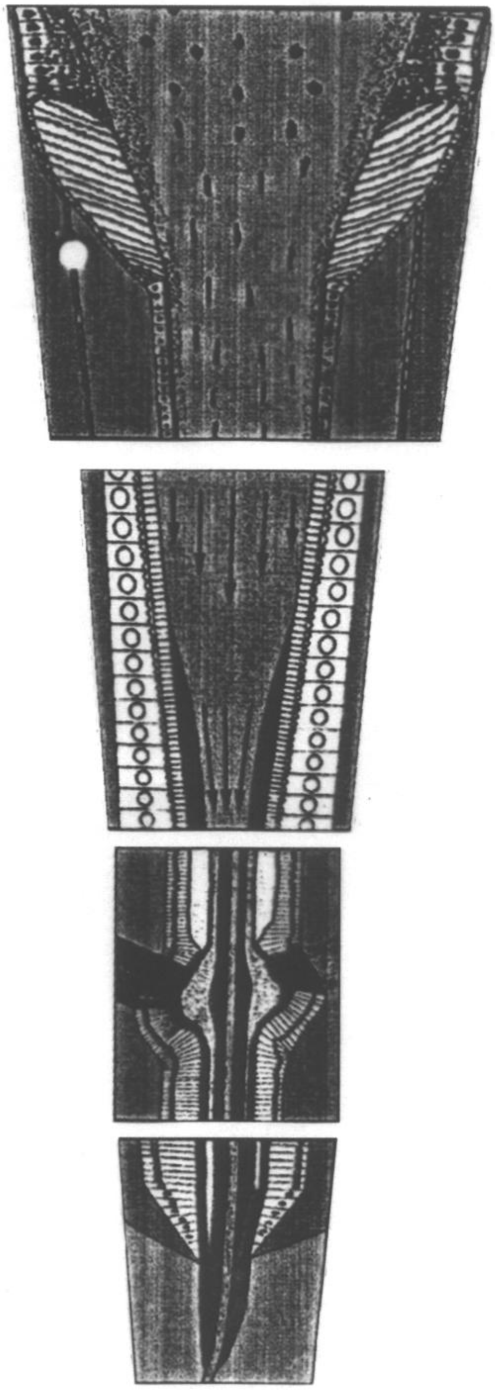


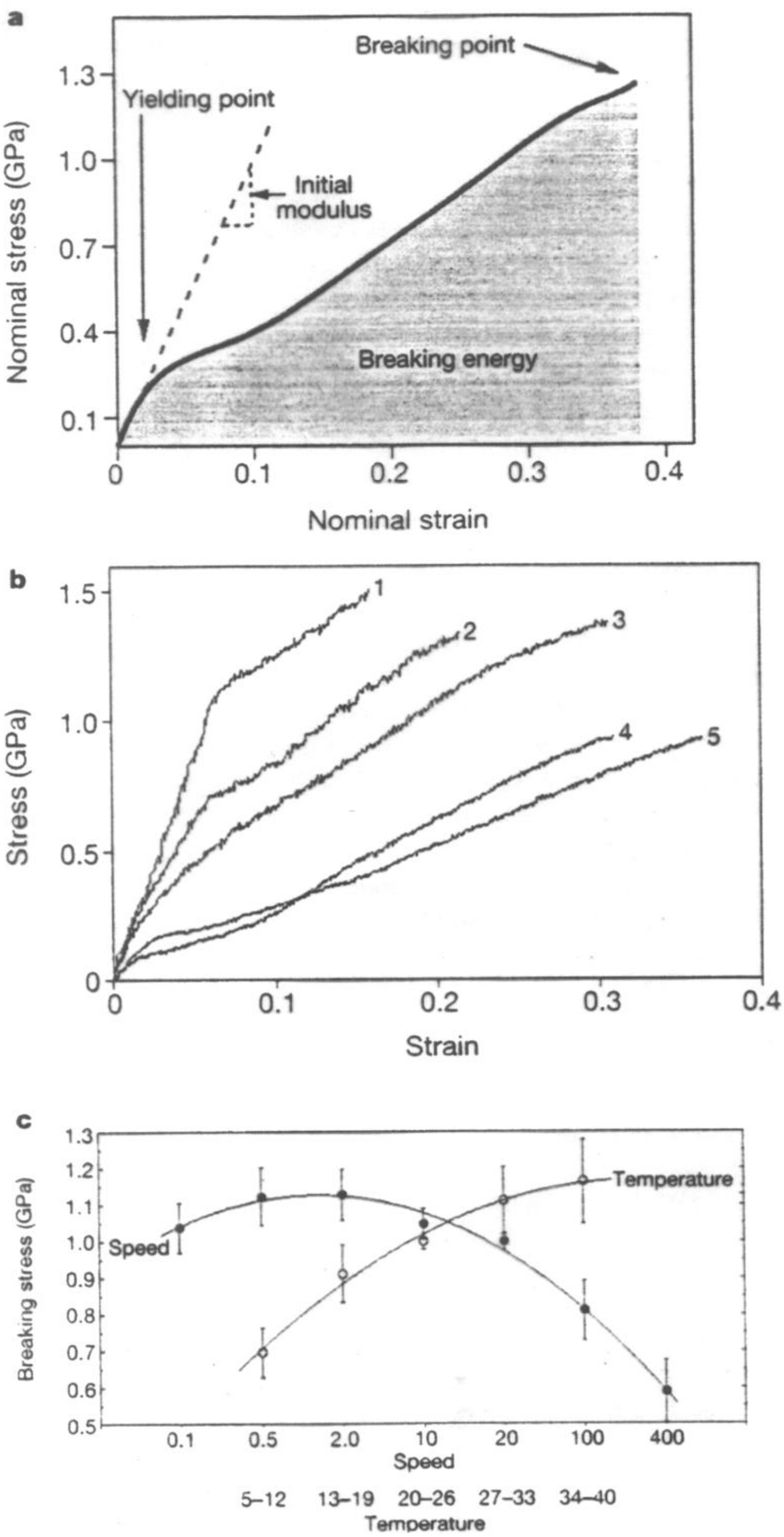


	spider silk Nephila edulis	high tenacity yarn 98 Kevlar 81
d, μm	3.35 ± 0.63	12
tensile breaking strain	0.39 ± 0.08	0.05
breaking stress, G Pa	1.15 ± 0.20	3.6
initial modulus, G Pa	7.9 ± 1.8	90

Kevlar is 3 times stronger
Spider silk is 5 times tougher
8 times more extendible

F.Vollrath, D.P. Knight, Nature, 2001, 110, 541-548




a
Breaking point
1.3
Yielding point
1.0
Initial
modulus
0.7
Nominal stress (GPa)
0.4
Breaking energy
0.1
0
0.1
0.2
0.3
0.4
Nominal strain
b
1.5
1
2
3
1.0
4
5
Stress (GPa)
0.5
0
0
0.1
0.2
0.3
0.4
Strain
c
1.3
1.2
Temperature
1.1
1.0
Speed
0.9
0.8
0.7
0.6
0.5
Breaking stress (GPa)
0.1
0.5
2.0
10
20
100
400
Speed
5–12
13–19
20–26
27–33
34–40
Temperature

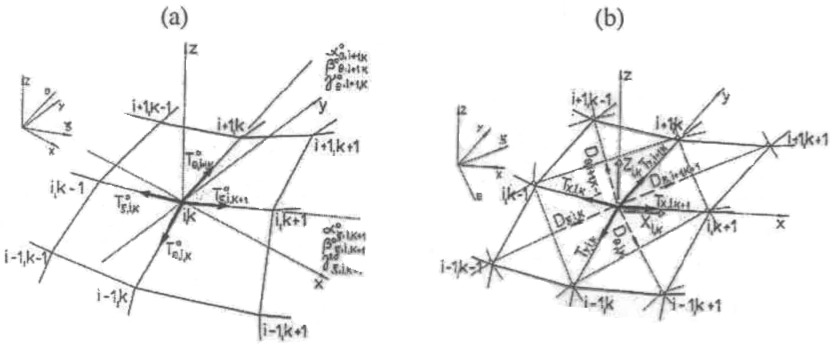


Fig. 7. Calculation schemes of the network knots of the roof system: (a) prestressed, not loaded, without cladding elements; (b) with the cladding elements $D_{i,k}$.

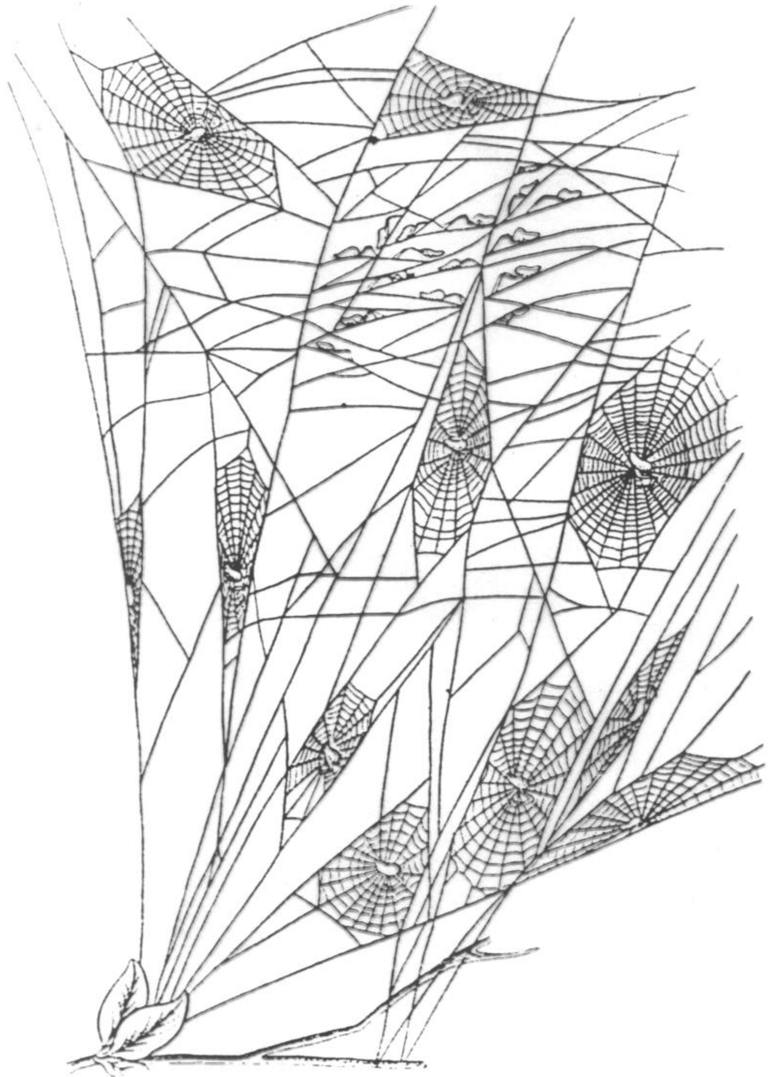
$$-T^0_{x,i,k}L_{x,i,k}+T^0_{x,i,k+1}L_{x,i,k+1}-\Psi_{x,i}(G_{x,i,k}-G_{x,i,k+1})-\Psi_{\xi,i,k}R_{\xi,i,k}A_{\xi,i,k}$$
$$-\Psi_{\theta,i,k}R_{\theta,i,k}A_{\theta,i,k}+\Psi_{\xi,i+1,k+1}R_{\xi,i+1,k+1}A_{\xi,i+1,k+1}+\Psi_{\theta,i+1,k-1}R_{\theta,i+1,k-1}A_{\theta,i+1,k-1}$$
$$+X_{i,k}=0,$$

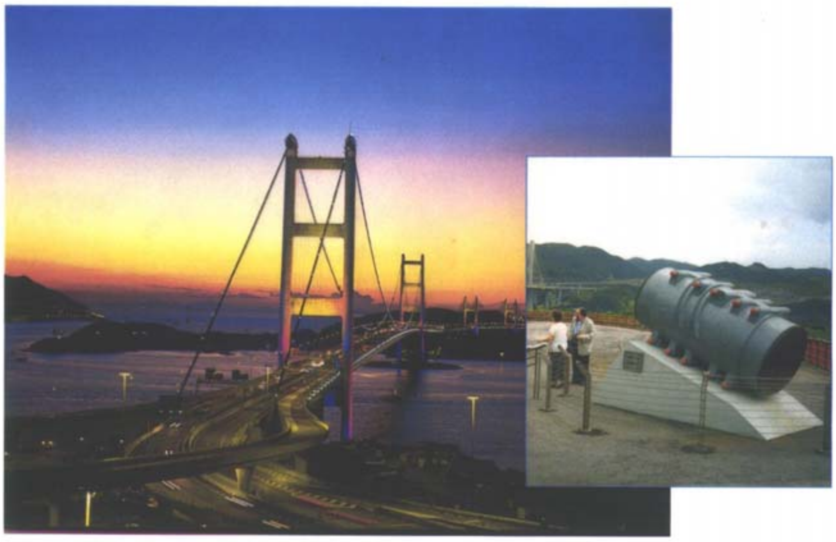
$$-T^0_{y,i,k}M_{y,i,k}+T^0_{y,i+1,k}M_{y,i+1,k}-\Psi_{y,k}(G_{y,i,k}-G_{y,i+1,k})-\Psi_{\xi,i,k}R_{\xi,i,k}B_{\xi,i,k}$$
$$-\Psi_{\theta,i,k}R_{\theta,i,k}B_{\theta,i,k}+\Psi_{\xi,i+1,k+1}R_{\xi,i+1,k+1}B_{\xi,i+1,k+1}+\Psi_{\theta,i+1,k-1}R_{\theta,i+1,k-1}B_{\theta,i+1,k-1}$$
$$+Y_{i,k}=0,$$

$$-T^0_{x,i,k}N_{x,i,k}+T^0_{x,i,k+1}N_{x,i,k+1}-\Psi_{x,i}(J_{x,i,k}-J_{x,i,k+1})-T^0_{y,i,k}N_{y,i,k}+T^0_{y,i+1,k}N_{y,i+1,k}$$
$$-\Psi_{y,k}(J_{y,i,k}-J_{y,i+1,k})-\Psi_{\xi,i,k}R_{\xi,i,k}C_{\xi,i,k}-\Psi_{\theta,i,k}R_{\theta,i,k}C_{\theta,i,k}$$
$$-\Psi_{\xi,i+1,k+1}R_{\xi,i+1,k+1}C_{\xi,i+1,k+1}+\Psi_{\theta,i+1,k-1}R_{\theta,i+1,k-1}C_{\theta,i+1,k-1}+Z_{i,k}=0, \tag{4}$$

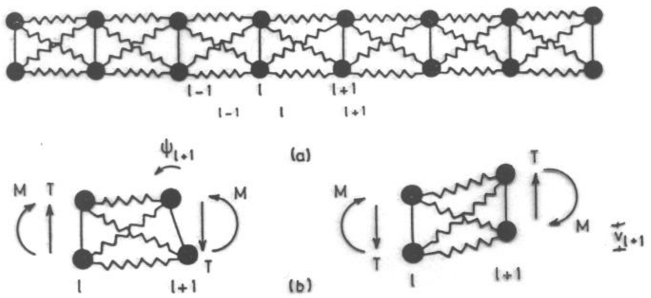
where

$\Psi_{\theta,i,k}=E_\theta\Omega_{\theta,i,k}$, $\Psi_{\xi,i,k}=E_\xi\Omega_{\xi,i,k}$,
$R_{\xi,i,k}=\Delta l_{Z,i,k}\big/[l^0_{\xi,i,k}(l^0_{\xi,i,k}+\Delta_{\xi,i,k})]$,
$l^0_{\xi.i.k}=[(a^0_{\xi.i.k})^2+(b^0_{\xi.i.k})^2+(c^0_{\xi.i.k})^2]^{1/2}$, $a^0_{\xi.i.k}=x^0_{i.k}-x^0_{i-1.k-1}$,
$b^0_{\xi.i.k}=y^0_{i.k}-y^0_{i-1.k-1}$, $c^0_{\xi.i.k}=z^0_{i.k}+z^0_{i-1.k-1}$,
$A_{\xi.i.k}=a^0_{\xi.i.k}+u_{i.k}-u_{i-1.k-1}$,
$B_{\xi.i.k}=b^0_{\xi.i.k}+v_{i.k}-v_{i-1.k-1}$, $C_{\xi.i.k}=c^0_{\xi.i.k}+w_{i.k}-w_{i-1.k-1}$,
$\Delta l_{\xi,i,k}=[a^0_{\xi,i,k}(u_{i,k}-u_{i-1,k-1})+b^0_{\xi,i,k}(v_{i,k}-v_{i-1,k-1})+c^0_{\xi,i,k}(w_{i,k}-w_{i-1,k-1})]\big/l^0_{\xi,i,k}$,





Näide 2. Escher



(a) Chain of dumbbells
(b) Transverse forces T and moments M induced for
pure rotation and translation.

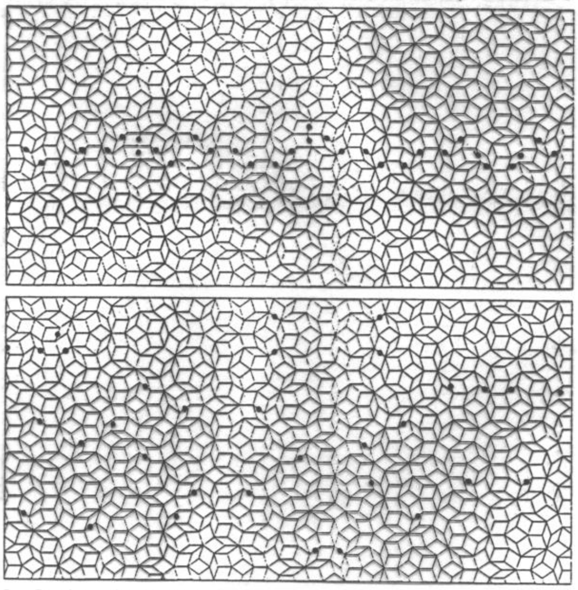
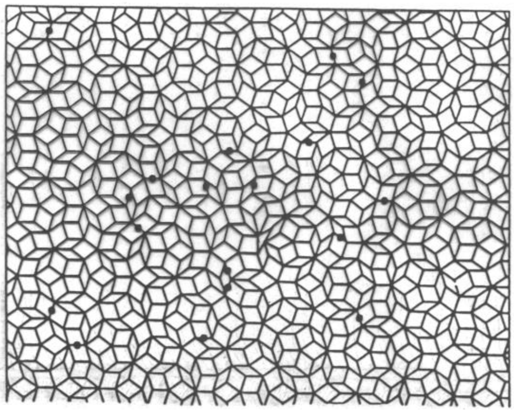


Figure 8. Section of a stacking fault in a two-dimensional Penrose lattice and its dissolution.



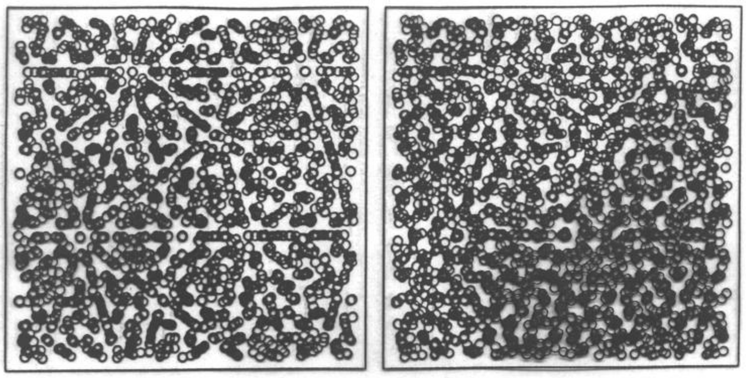


Figure 4. Three-dimensional quasi-crystal of the monoatomic primitive decoration. Left-hand side: Projection after 400 iteration steps. Atoms have aligned in clearly visible planes with two different spacings of ratio $\tau : 1$. Right-hand side: The same quasi-crystal after 800 iteration steps. The planar structure has decayed almost completely, only single vertices, which had been centres of perfect icosahedral neighbourhood, have survived.

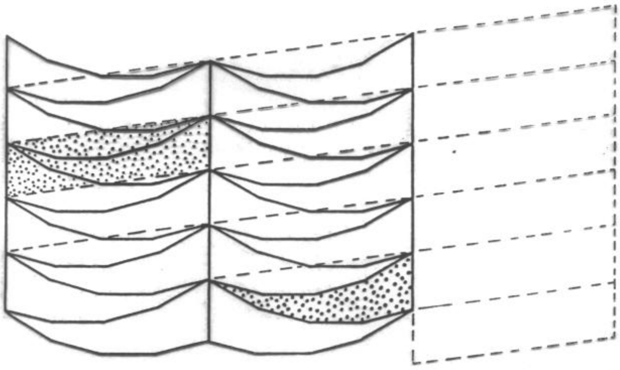
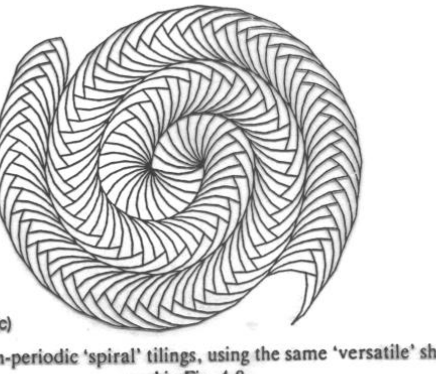


Fig. 4.8. A periodic tiling, illustrated in relation to its period parallelogram.



(c)

Fig. 4.9. Three non-periodic 'spiral' tilings, using the same 'versatile' shape that was used in Fig. 4.8.

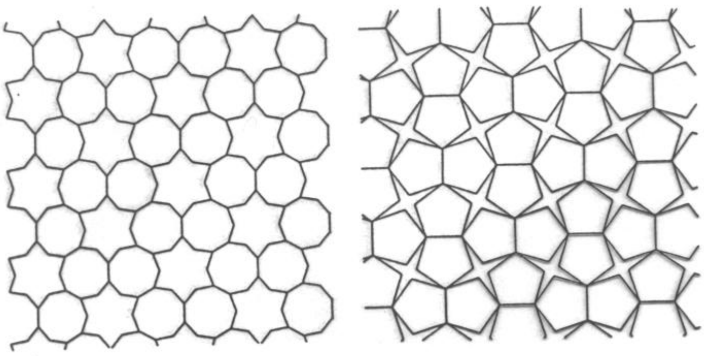
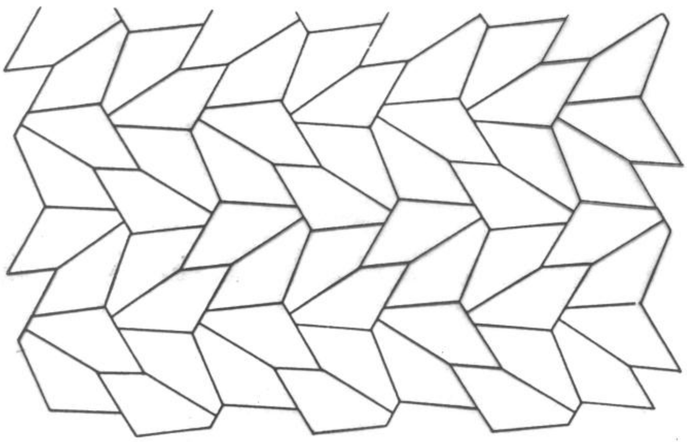


Fig. 4.7. Two examples of periodic tilings of the plane, each using two shapes.



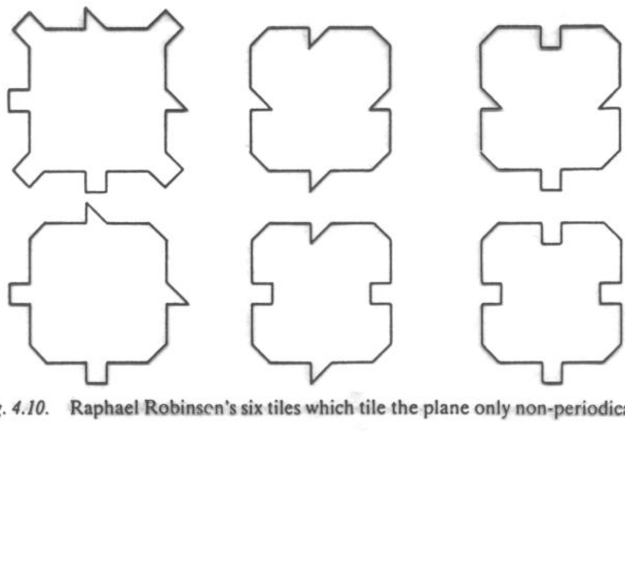
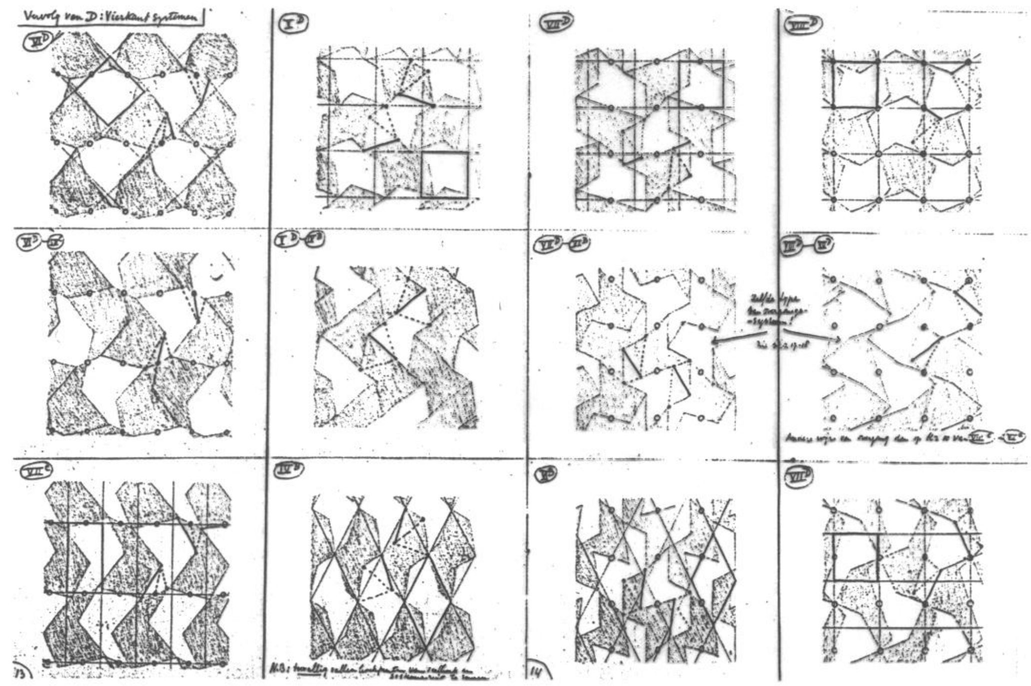


Fig. 4.10. Raphael Robinson's six tiles which tile the plane only non-periodically.



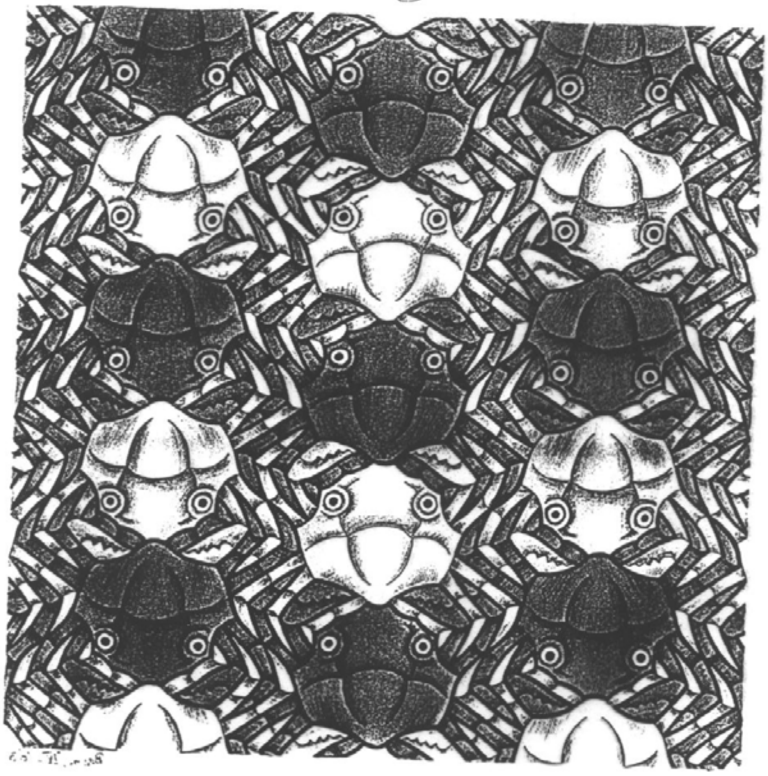
continuation of D: Square systems

VI^{D}	V^{D}	VII^{D}		$VIII^{D}$
VI^{D}-VII^{C}	V^{D}-IV^{B}	VII^{D}-VI^{B}	same type of transitional system! see pp. 17–18 a different way of transition than that on p. 10 from $VIII^{C}$ to VII^{C}	$VIII^{D}$-VII^{D}
VII^{C}	IV^{B} N.B. *by chance* the vertices of the polygon [motif] and system rhombus coincide.	VI^{B}		VII^{D}

Baarn III-'67

(127) system I^D
apparently 2-sided symmetric motif

(11)



Vrije schikking, gegrond op identiek systeem, met 36 verschillende motieven. Baarn III-'51