Aesthetic dimension of physics

Reinhold A. Bertlmann
Faculty of Physics, University of Vienna

Cartographies of sensation
Symposium, 14 – 15 Nov 2008, Vienna
Abstract

Aesthetics as a sensual perception plays an important role in the construction of a physical theory and is not considered to be in contrast to mathematical rationalism.

On the basis of quantum theory the aesthetic dimension of physics will be demonstrated. In particular, it will be shown how the quantum states of modern quantum information, the entangled states of the observers Alice and Bob, can be illustrated in an abstract space which exhibits an amazingly simple and elegant geometry.
aesthetics as sensual perception
plays important role in construction of physical theory

representatives of view of aesthetics:
Einstein
Dirac
Feynman
Chandrasekhar
Penrose

“it’s better to develop beautiful equations than just to adapt equations to experiment”

aesthetics
• no beautiful byproduct
• but essential part of scientific theory
in science
- feeling for aesthetics  “no science without beauty”  similar to art
- connection between correctness – beauty

aesthetics
as sensual form of knowledge or cognition
awakening eros
is not in contrast to rationality
creativity, inspiration
or logical construction of theory

mathematical rationality per se
mathematical construction
is highly aesthetic!
not just the abstract symbols
symbols
with their emotional content
geometric illustration
Aesthetics in science

- **elegance** in constructions, solutions, proofs
  - don't construct an ugly theory,
  - solutions & proofs beautiful, i.e. clever idea behind!

- **simplicity** in description
  - don't describe theory in complicated way,
  - do it most simple!

- **economy** theory concise, optimal
  - theory must contain all elements – nothing is missing,
  - but without unnecessary frills!

- **efficiency** in reaching aim
  - solutions must be found without detour – straightforward!
Quantum theory

quantum theory

highly aesthetic    satisfying requirements for aesthetics
although not understood
    from an “anschaulich” physical point of view
    from everyday experiences
but as mathematical formalism – just perfect
    in accordance with experiment
formalism is complete
    there is no element of reality missing

theory
the more abstract – the more correct !?
Schrödinger Equation

fundamental theory of quantum mechanics
Schrödinger equation

\[ H\psi = i\hbar \frac{\partial}{\partial t} \psi \]  \hspace{1cm} \text{time dependent}

\[ H\psi = E\psi \]  \hspace{1cm} \text{stationary}

Hamilton operator

\[ H = -\frac{\hbar^2}{2m} \Delta + V \]

\[ \Delta \] \hspace{1cm} \text{Laplace operator, double differentiation}

\[ \uparrow \hspace{0.5cm} \uparrow \]

kinetic potential energy

\[ E \] \hspace{1cm} \text{total energy}

- calculable
- to be compared with experiment

21.11.2008

Reinhold A. Bertlmann
Quantum state

\( \psi(x) \) \quad \text{wavefunction}

represents state of quantum system
contains all information about system

\( \psi^* \psi \) \quad \text{probability for finding system in quantum state}

\( \psi^* H \psi \) \quad \text{expectation value for energy}
States as points

representation of state – wavefunction as points in Hilbert space

mapping of wavefunctions into points of a line, 1–dimensional space or into points of 3–dimensional space (more general)
Spin

spin of particle

up

rotation
as classical analogue

down

spin measured by magnets
along 2 directions

21.11.2008

Reinhold A. Bertlmann
Two particle quantum state

quantum state of 2 particles with spin

particles measured by Alice and Bob
Quantum information

quantum information & quantum communication

new kind of phenomena like quantum teleportation

ingredient:
entangled quantum states
Entangled states

Entangled states of quantum information

possible states:
- entangled
- separable

outcome of Alice influenced by Bob
not influenced

EPR-type experiment

Einstein-Podolsky-Rosen

21.11.2008
Reinhold A. Bertlmann
Illustration of geometry

Geometry of space of quantum states
in 2x2 -1 = 3 dimensions

Quantum states within tetrahedron

time reversal on one spin  – Bob separable states invariant

21.11.2008
Reinhold A. Bertlmann
Geometry of quantum states

in $2 \times 2 - 1 = 3$ dimensions

intersection of tetrahedrons $\rightarrow$ separable states – double pyramide
entangled states – outside

simple & elegant geometry!