Scientific research methods

Definition of Science and Its Stages of Development

"Science is the attempt to make the chaotic diversity of our sense-experience correspond to a logically uniform system of thought." — Albert Einstein

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Course Context

Introductory block of the course

Prepares doctoral students to understand science as a form of social practice

Positions research within the logic of scientific development

Supports planning, management and presentation of research

Learning outcomes

Define science using an integrated approach

Identify features and functions of science

Explain historical stages in the development of science

Compare classical, non-classical and post-non-classical science

Relate current physics research to contemporary stage of science

Why We Need the Definition?

PhD research must fit into the system of scientific knowledge

Expertise, funding and peer review ask about scientific novelty

To justify novelty, we must answer: what counts as science?

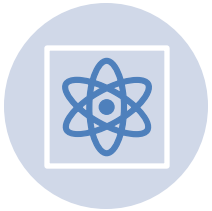
Basic Definition of Science

Science – socially organized, methodologically regulated activity

Aim: to obtain objective, systematically structured and verifiable knowledge about reality

Components: activity, knowledge, organization, method, verification

Alternative Views of Science



Science as knowledge – system of concepts, laws, theories

Science as activity – method-driven search for truth

Science as institution – universities, academies, journals, labs

Science as culture – norms, ethics, authorship, priority

Integrated definition: science = knowledge + method + community

Main Features of Science

- Objectivity and rationality
- Systematic and cumulative character
- Reproducibility and verifiability/falsifiability
- Communicativeness – publication, peer review

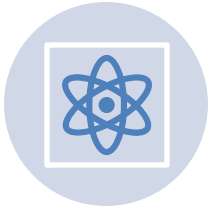
Functions of Science

Cognitive – produce new knowledge

Explanatory – reveal laws and mechanisms

Predictive – forecast phenomena

Practical/technological – basis for innovation



Worldview/methodological – scientific picture of the world

Educational – preparation of researchers

Why Talk About Stages?

SCIENCE IS NOT STATIC

METHODS AND OBJECTS CHANGE OVER TIME

STAGES HELP JUSTIFY CHOSEN METHOD

STAGES EXPLAIN LIMITS OF CURRENT PARADIGMS AND RESEARCH FRONTIERS

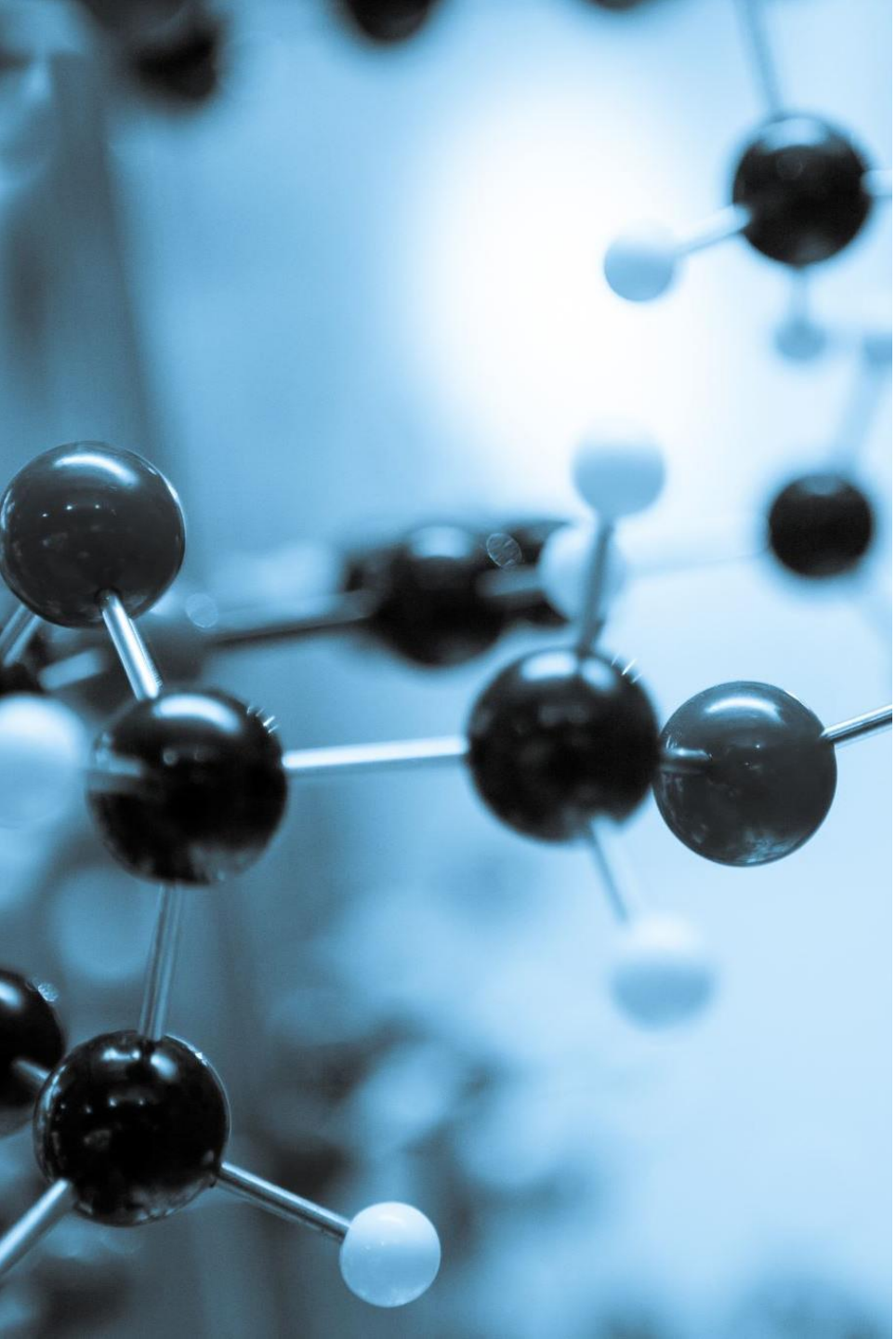
General Periodization

1. PRE-SCIENTIFIC / PROTO-SCIENCE

2. CLASSICAL SCIENCE (17TH–19TH C.)

3. NON-CLASSICAL SCIENCE (20TH C.)

4. POST-NON-CLASSICAL / CONTEMPORARY SCIENCE (LATE 20TH–21ST C.)



1) Pre-scientific Stage

- Knowledge in myth, religion, art, craft
- Empirical rules in astronomy, medicine, metallurgy
- Not yet systematic, not experimentally justified
- No specialized research institutions
- Created conceptual seeds for later science

2) Classical Science (17th–19th c.)

Subject–object split, neutral observer

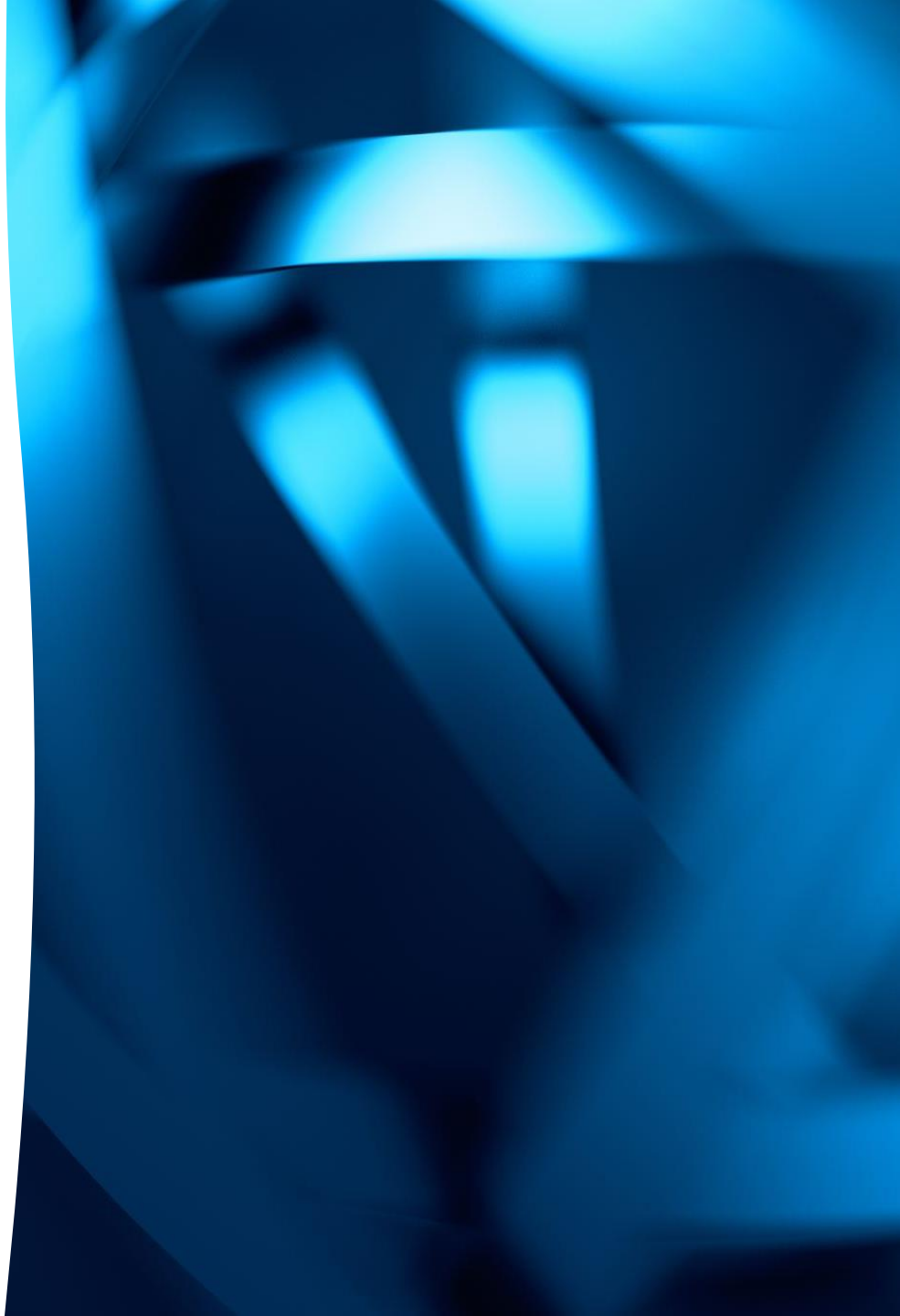
Mechanistic picture of the world

Mathematization of nature

Experiment as criterion of truth

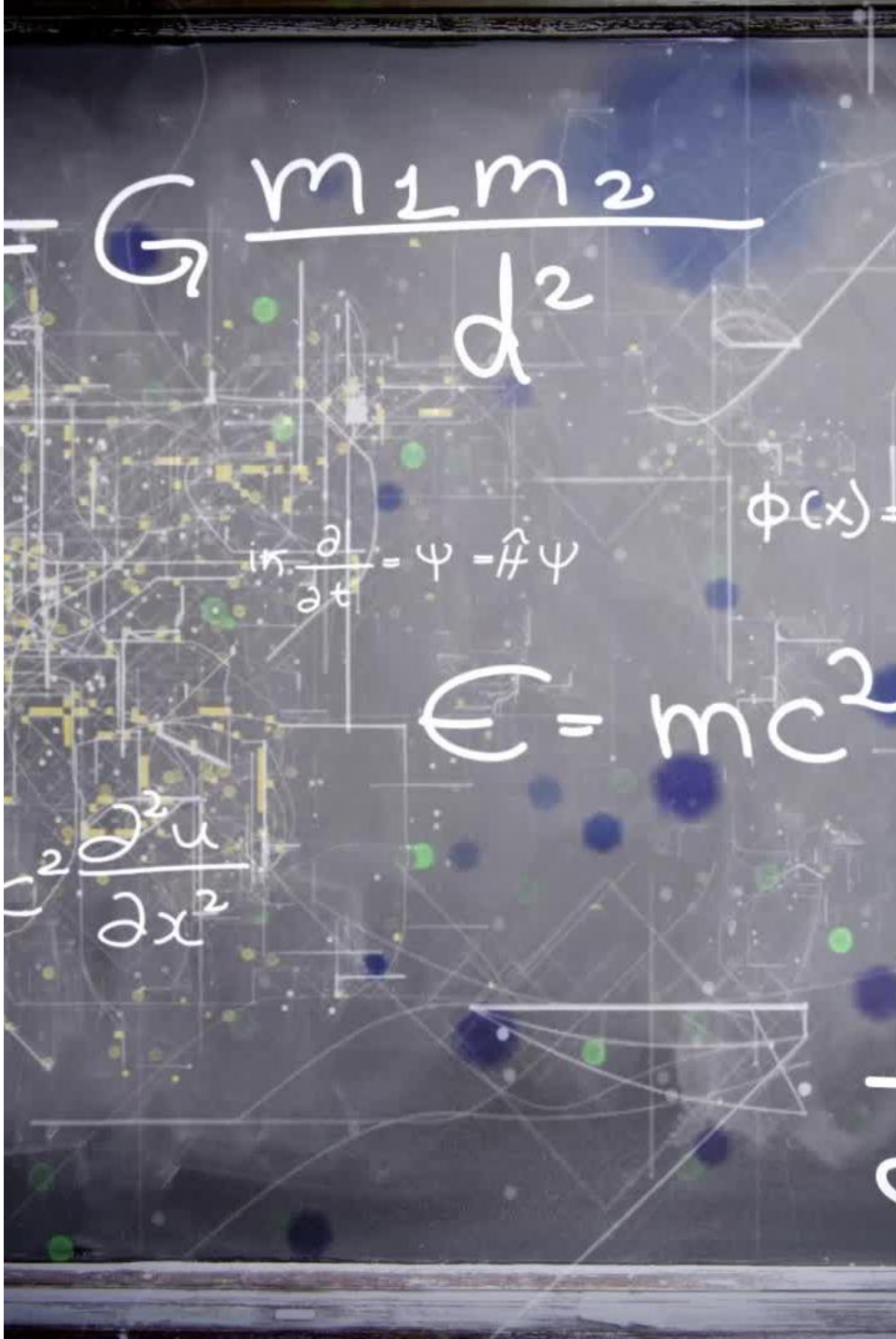
Determinism and ideal of universality

Key figures: Galileo, Descartes, Newton, Huygens, Maxwell



3) Non-classical Science (20th c.)

- Relativity → role of observer, frame of reference
- Quantum mechanics → probability, uncertainty, measurement
- Subject included in description
- Multiple equivalent models
- Probabilistic and statistical approaches
- Limits of classical determinism



4) Post-non-classical / Contemporary Science

- Complex, open, self-organizing systems
- Interdisciplinarity (physics + chemistry + biology + IT + materials science)
- Technoscience: experiment + technology + computation + visualization
- Big science, data-intensive research, international collaborations
- Ethical and social dimensions included
- Project-based research management

Scientific Revolutions (Kuhn)

Normal science → anomaly → crisis → new paradigm

Paradigm = model problems + methods + standards

Physics examples: Newtonian mechanics → relativity, quantum theory

PhD: clearly state your paradigm

Drivers of Scientific Development	New empirical data (new instruments)
	Internal contradictions of theory
	Technological and societal requests
	Funding and organization of science
	Communication of scientific community

Place of Physics in This Evolution

Classical: mechanics, electrodynamics, thermodynamics

Non-classical: quantum mechanics, relativity, nuclear physics

Post-non-classical: plasma physics, nanotechnology, astrophysics, computational physics

Physics as method-giver for other sciences

Implications for PhD Research

Indicate the stage of science your problem belongs to

Define the type of object (closed, open, complex, socio-technical)

Choose adequate methods (experiment, modeling, simulation, data-driven)

Show novelty as contribution to current stage

Indicate limitations (measurement, uncertainty, ethics)

Questions for Self-Check

- Can I define science as activity + method + institution?
- At which stage does my topic stay?
- Which scientific features do I use in my research design?
- Which paradigm do I follow?
- Is my object simple or complex?

Suggested Literature

- T. S. Kuhn, The Structure of Scientific Revolutions
- I. Lakatos, The Methodology of Scientific Research Programmes
- M. Polanyi, Personal Knowledge
- B. Latour, Science in Action
- National/university standards for doctoral dissertations