Lukas Mairhofer

Interference

Proposal of a Methodological Metaphor

Abstract: The strict separation of the humanities and the sciences, especially of literature and physics and more generally of different fields of knowledge, has recently come under severe criticism. It is increasingly understood that their interaction plays an important role in the development of scientific concepts as well as philosophical and literary production. However, a methodological approach to this interaction has yet to be developed. Here I propose the metaphor of interference to describe the relation of different fields of knowledge. First, interference is introduced as an epistemological metaphor as it is applied in Science and Technology Studies. Interference describes a type of interaction where the entities are constituted in the interaction rather than preceding it. The concept is then transferred to the interaction of fields of knowledge, where the notion of interference allows us to state a necessary condition for the interaction of different disciplines: the coherence of their fundamental entities. Furthermore, the application of a wide range of methods to one and the same problem is implied in this metaphor. Bertolt Brecht and his interference with quantum physics will be responsible for the storyline as well as the exemplification of the proposed approach.

1 Heisenberg's microscope

Helsinki in winter: That amounts to four hours of sunlight per day, the temperature of the air stays well below the freezing point of water and the railway station is one of the more noticeable buildings in the city. It is in this railway station that, in Bertolt Brecht's *Refugee Dialogues* [*Flüchtlingsgespräche*], two German emigrants meet to discuss the state of the world: The worker Kalle and the physicist Ziffel. They talk about their emigration, about fascism and about the big economic crisis which preceded it. When he describes his difficulties understanding this crisis, Ziffel suddenly introduces quantum physics into the conversation:

The investigation of the situation meets strange challenges. I have to think about an experience of modern physics, Heisenberg's uncertainty factor. This is about the following: Research on the atomic world requires very strong lenses in order to be able to see the processes among the smallest particles. The light in the microscopes has to be so strong that it causes heating and destruction in the atomic world, true revolutions. Just that

which we want to observe we set on fire by observing it. Therefore we do not observe the normal life of the microcosmic world, but a life disturbed by our observation. In the social world similar phenomena seem to exist.¹ (Brecht 1967, Vol. 14, 1420)

“Heisenberg’s uncertainty factor” refers to the uncertainty relation which Werner Heisenberg formulated in 1927. He establishes it heuristically in a *Gedankenexperiment*, the γ -ray or Heisenberg microscope (Heisenberg 1927, 174–175). Indeed the light in this microscope causes “heating and destruction,” although these effects depend on the wavelength of the light rather than on its intensity, as implied by Brecht. The resolution of a light-microscope is given by $\Delta x = \lambda/2\sin \varepsilon$, where Δx is the smallest resolvable distance, λ the wavelength of the light and 2ε the acceptance angle of the objective (see Fig. 1). When very small objects like an electron are to be resolved, the wavelength of the light should be small, as for gamma-rays. But light with a short wavelength will transfer a large momentum to the electron. In the lens system different momentum-states of the photon cannot be distinguished and thus after the scattering event, we might know where the electron was but not where it goes, that is, what momentum it has. Heisenberg concludes that in quantum physics position and momentum are incommensurable, as the respective measurements disturb one another and cannot be performed simultaneously.

Fig. 1: Illustration of the γ -ray microscope based on Heisenberg’s own drawings (Heisenberg 1930). © Provided under the Creative Commons licence by Bryan W. Roberts.

1 Transl. by LM. “Der Untersuchung der Situation stellten sich eigentümliche Schwierigkeiten in den Weg. Ich muß hier an eine Erfahrung der modernen Physik denken, den Heisenbergschen Unsicherheitsfaktor. Dabei handelt es sich um folgendes: die Forschungen auf dem Gebiet der Atomwelt werden dadurch behindert, daß wir sehr starke Vergrößerungslinsen benötigen, um die Vorgänge unter den kleinsten Teilchen der Materie sehen zu können. Das Licht in den Mikroskopen muß so stark sein, daß es Erhitzungen und Zerstörungen in der Atomwelt, wahre Revolutionen, anrichtet. Eben das, was wir beobachten wollen, setzen wir so in Brand, indem wir es beobachten. So beobachten wir nicht das normale Leben der mikrokosmischen Welt, sondern ein durch unsere Beobachtung verstörtes Leben. In der sozialen Welt scheinen nun ähnliche Phänomene zu existieren” (Brecht 1967, Vol. 14, 1420).

This challenges the notion of causality founded on classical physics, where from the initial values of a system in position and momentum space (phase space) all future behavior of the system could be derived. It seemed possible to infer a strict determinism from physics. In quantum physics, however, the determination of the initial conditions themselves is not possible.

Bohr, whom Brecht met later during his exile in Denmark (Bunge 1985, 98), was not happy with the analysis of his protégé Heisenberg, and published several correcting statements (Bohr 1961). He argues that already in classical physics the interaction of the particle with its environment during the measurement process influences the results. In thermodynamics, for example, a measurement of the temperature of a system will change its temperature as this measurement is defined as a transfer of heat (Heisenberg 1969, 147–148). Heisenberg applies this description to the level of atomic processes, where the influence of the observation can no longer be ignored, but Bohr criticizes Heisenberg's failure to understand the extent of the difference between classical and quantum physics. Bohr describes the relation between observables that are correlated classically but cannot be measured simultaneously in quantum mechanics with the notion of complementarity: The measurement interaction constitutes the properties of its subject as well as of its object in the first place, and is not a mere disturbance of these properties. Heisenberg takes his entities to be colliding particles, but in quantum physics the interaction of the electron with light is better described as an interference of waves. Bohr's argument could be put as follows: In quantum physics any measurement is an interference of apparatus and object. Although we interpret the result of the observation as the properties of the object, it in fact depends as much on the apparatus as on the object. Complementary properties such as momentum and position correspond to complementary measurement processes, without which they lack any meaning.

Interference results from the superposition of waves that form a common oscillation, canceling out and enhancing one another. This kind of interaction is not possible for the particles of classical physics, which are defined by impenetrability and non-diverging localization. The source of the superimposing waves can be stones thrown into a lake or light diffracted from a CD, but can also be the slits of a grating diffracting an incoming wave (see Figs. 2 and 3). In this case we can derive the properties of the wave from the interference pattern, if the grating mask is well-known, and on the other hand we can investigate the mask with a well-known wave.

With Heisenberg's microscope, Brecht picks up a thought experiment that had just been developed in contemporary physics and applies it to social phenomena. Thought experiments are readily accessible for such transfers, as they

Fig. 2: Plane water-waves incident on an obstacle. Curved wave-fronts emanate from gaps in the obstacle, overlap and interfere. In this case the screen on which the fringe pattern is projected is formed by the sandy beach whose contour clearly shows the maxima and minima of the intensity of the incidenting water-waves. © Lukas Mairhofer.

are used in science as well as in philosophy and literature, as Macho and Wunschel's collection *Science & Fiction* shows. The editors, however, take thought experiments to be purely literary fiction and thus anti-performative:

Because in the thought experiment the plan, the mental experimental setup, merges with its realization in the empirical experiment. We can assess the consequences of a counterfactual assumption, a strategic alienation, only in our heads; and it is only possible to document these consequences in a narration.² (Macho and Wunschel 2004, 11)

² Transl. by LM. "Denn im Gedankenexperiment verschmilzt der Plan, die mentale Versuchsanordnung, mit seiner Durchführung, dem empirischen Experiment. Wir haben nämlich gar keine Möglichkeit, die realen Konsequenzen in einer kontrafaktischen Annahme, einer strategischen Verfremdung, anders zu überprüfen als im Kopf; und wir können diese Konsequenzen in keiner anderen Form dokumentieren und überprüfbar machen als durch irgendeine Art von Erzählung" (Macho and Wunschel 2004, 11).

Fig. 3: Simulation of the interference of two waves that form behind a double slit. © Provided under the Creative Commons licence.

In physics, however, the development of technical possibilities and experimental procedures has allowed us in the last four decades to realize in the laboratory a series of thought experiments that were put forward in the early stages of quantum mechanics to investigate fundamental philosophical questions arising from the new physics. Tests of Heisenberg's microscope are being conducted as PhD projects (Dopfer 1998), and the diffraction of large and complex biomolecules at a grating forces them into a superposition of passing through the left and the right slit (Gerlich 2007). This can be translated into Schrödinger's cat if the left slit is associated with destroying the molecule and the right slit with the molecule surviving intact. As a third example, take the EPR-paradox, which Einstein, Podolsky and Rosen developed in 1935 to prove that quantum physics was incomplete, that it did not contain a description of all determining factors acting in the microscopic world. The alternatives were that either causality was violated or the speed of light was not the greatest speed. They considered an entangled pair of objects, which comes from a common source and shares certain properties (for example momentum, polarization or spin) in such a way, that the property is not known before the measurement, but because they are entangled, the measurement of one object will at the same moment give us all the information about the state of the other object (Einstein 1935). Many experiments (see for example Aspect 1982) have been conducted

that seem to prove that no such hidden parameters exist and indeed the measurement of the first object determines the properties of the second. But it turns out that the transmission of information still requires a classical channel not exceeding the speed of light. However, entangled quantum systems allow us to set up, for example, communication secure against any eavesdropping, and will soon allow us to crack any encryption based on factorization such as RSA256 without effort (Shor 1997; Ekert 1991). These experiments concern the ontological and epistemological status of the physical world and some physicists now dare to speak of “experimental metaphysics” (Shimony 1984, 36).

Brecht also aims at the realization of thought experiments in the epic theater. In his description of the relation between the audience and the stage, Heisenberg’s microscope appears again (Brecht 1967, Vol. 16, 577). In this way the epistemological function of the experiment in physics is transferred to aesthetic problems and Heisenberg’s microscope unfolds its rich and far-reaching implications, as Hans Blumenberg has predicted for such “absolute metaphors” (Blumenberg 2010, 14–15). Absolute metaphors contain in themselves an epistemological model that tells us how to reflect about a certain entity and its relations to other entities. Formal logic offers no appropriate means to tackle such a metaphor, which itself contains a decision about the assignment of truth values. As a metaphor it transfers this rule of reflection about a known set of entities (in our case this is, somewhat surprisingly, Quantum Physics) to another set of entities (the Epic Theater). Heisenberg’s microscope follows a long tradition of images in which light figures as an expression of truth. This tradition can be traced in western philosophy from Plotinus (Dijksterhuis 1983, 52) to Hegel (1970 [1930], 111–125). The positive reference of the enlightenment to truth is inverted in the twentieth century in Foucault’s *Panopticon*. In the prison under total surveillance, vision takes over the role of light. In this way, truth is turned into a question of power and exhaustive knowledge becomes associated with a totalitarian regime (Foucault 1979).

The light metaphor of truth is intertwined with an epistemic theory that itself has a long history. With diverging implications, it is formulated in Plato’s allegory of the cave, which describes our cognition as the shadows of the pure ideas (Plato 1962, 224–227), as well as in the Aristotelian wax-metaphor, in which objects imprint their traces on our minds as on a sheet of wax (Aristotle, *De anima*, 429b29–430a2). Descartes picks up the metaphor of wax in his *Meditations* (Descartes 2011, 156–160), and in the *Empiricriticism* Lenin proposes

the theory of reflection with an intention that is strictly opposed to that of Plato: “Materialism is the acknowledgement of the objective laws of nature and their approximately correct representation in the human mind” (Lenin 1970, 176).³

This volume contains a valuable study by Nikola Kompa on the epistemic role that metaphors play in scientific cognition.⁴ The transfer of scientific knowledge to other fields of knowledge, however, is not discussed. Hans Blumenberg describes a transfer of physical theories as metaphorization of scientific concepts and has extensively investigated such a transfer using the example of the Copernican Revolution (Blumenberg 2010, 99–107). But there is a fundamental difference in our case: The Copernican Revolution took place before the specialization and separation of the sciences. The history of this specialization has many layers and happened asynchronously in different countries (Daston 1998). At the beginning of the twentieth century, however, the separation of the humanities and the natural sciences had been completed in Germany. How can such a metaphorization take place in modernity, then – how can the translation between physics and literature work at all? Brecht himself seems to warn us not to take him all too seriously: “How little knowledge one has to pick up to create the impression of profound science on stage” (Brecht 1973, 205).⁵ Is Brecht using his reference to quantum physics just to enrich his figure a little bit and give his text the flavor of a certain depth?

2 Interference as methodological metaphor: Interference vs. reflection

With Heisenberg’s microscope, Brecht questions the status of our cognition: In this microscope it is impossible to perceive objects objectively, as the perceiving subject becomes part of the experimental setup and thus enters the result of the perception. The composer Hanns Eisler, who was a close friend

3 Transl. by LM. “Die Anerkennung der objektiven Gesetzmäßigkeit der Natur und der annähernd richtigen Widerspiegelung dieser Gesetzmäßigkeit im Kopf des Menschen ist Materialismus” (Lenin 1970, 176).

4 Cf. Nikola Kompa’s paper “Insight by Metaphor – the Epistemic Role of Metaphor in Science” in this volume.

5 Transl. by LM. “wie wenig aufgeschnapptes wissen gehört dazu, auf der bühne den anschein tiefer wissenschaft zu erwecken” (Brecht 1973, 205).

of Brecht, later described the important role that the thought experiment played in their discussions:

When Heisenberg says that the object of the perception is altered by the method of perception, so that we cannot perceive it with absolute precision – that is approximately exactly right –, yeah well, for us that is simply a people's fair.⁶ (Bunge 1970, 153)

The metaphor of the γ -ray microscope differs radically from the classical light metaphors of truth. In this microscope, truth is the result of a production and not given by epiphany or reflection, it is performative and not reflective. As it is an experimentally produced truth, it is an approximate and preliminary truth. As early as in the early 1930s Brecht formulated his critique of the theory that reality is merely reflected in the subject:

Nor are the philosophers like buckets full of water which always reflect the same moon, as clearly as clear as they are being water. From a comparison of the mirror and the reflected image one can know neither the head nor the world, and that is mainly because the heads change the world according to their purposes.⁷ (Brecht 1988–2000, Vol. 21, 564)

With Heisenberg's microscope, the epistemological concept of reflection becomes highly problematic, since now the result depends on the purpose of the investigation. The physicist and philosopher of science Karen Barad notes: "In the twentieth century, both the representational or mimetic status of language and the inconsequentiality of the observational process have been called into question" (Barad 2007, 97). She proposes replacing the metaphor of truth as reflection of reality with the metaphor of an interference between subject and object (Barad 2007, 71). With this suggestion she extends a concept that Donna Haraway has put forward in her criticism of the representational character of language (Haraway 1992). Barad deliberately maintains the optical metaphors of the epistemological process, but she explicitly points out that the concept of interference implies a shift from classical optics to quantum optics (Barad 2007, 81–86). In quantum optics truth is "performative" (Barad 2007, 33), while the image in the mirror is thought to be a neutral representation. This epistemic

⁶ Transl. by LM. "Wenn er [Heisenberg] sagt, daß sich das zu Erkennende durch die Methode der Erkennung verändert, so daß wir es nicht genau erkennen können – das stimmt ungefähr genau –, ja das ist für uns ein einfaches Volksfest" (Bunge 1970, 153).

⁷ Transl. by LM. "Die Philosophen sind auch nicht wie mit Wasser gefüllte Eimer, die immer den gleichen Mond spiegeln, und zwar so klar, wie sie als Wasser eben klar sind. Aus einem Vergleich des Gespiegelten und des Spiegels kann man weder die Welt noch den Kopf erkennen, und zwar hauptsächlich, weil die Köpfe gewisser Zwecke wegen die Welt, die ja immer verschieden ist, noch dazu in ihrer Darstellung, veränderten" (Brecht 1988–2000, Vol. 21, 564).

metaphor holds for a vast range of scientific knowledge as not only quantum physicists experience their influence on the investigated process. The anthropologist in the field, for example, should well be aware that what he or she observes is not an unperturbed social system. As Ursula Rao and Stefanie Mauksch argue, field work is based on dialogue with the subjects of interest and this dialogue always constitutes an intervention rather than a passive observation (Mauksch 2014). For biology Astrid Schrader makes an interesting case: The *dinoflagellae Pfiesteria piscicida* thrives in water containing high levels of nutrients caused by extensive animal farming and was linked to massive fish killings. This triggered a long-lasting quarrel as one side provided experimental evidence for the toxicity of the *dinoflagellae*, but this evidence could not be reproduced by others. After two decades it became clear that the microorganism morphs into a toxic form only in the presence of fish and given specific environmental conditions. Thus the mode of observation determined the behavior of the investigated object, i.e. whether the poison could be found at all (Schrader 2010).

In order to become accessible, however, the interference has to be projected onto a screen – it has to be represented. This step Barad seems to ignore. To account for the many possible representations of one and the same interference, she introduces the concept of an intra-action between wave and mask. In this intra-action several cuts are possible, which will decide what is part of the experimental setup (the apparatus) and what is part of the object. Consider for example the cane that a blind person uses for orientation. This cane is an instrument through which he or she perceives the world, but it can itself immediately become the object of investigation, when the blind person sits down and starts to check it with their fingers for scratches or fractures. I think, however, that this cut itself acts as a projection, and that representation cannot be omitted in epistemological processes. In my understanding, the cut can only be enacted with regard to a third, the screen. The representation then yields an interference pattern that depends not only on wave and mask, but also on the distance to the screen and its properties, such as its resolution. With respect to this distance, different regimes can be distinguished. In the near-field the waves emanating from the mask superpose in such a chaotic way that the resulting pattern cannot be calculated exactly (i.e. analytically) (Case 2009). At certain distances, however, a pattern evolves and the shape of the mask is reproduced. In the far-field, on the other hand, the resulting fringe pattern shows a central maximum and washed out sidepeaks – the image has become blurred and multi-faceted (i.e. Fig. 4).

Fig. 4: The left picture shows the transition from the near- to the far-field. In the near-field the mask is reproduced at certain distances. At larger distances from the grating a far-field pattern evolves with a central maximum and several sidepeaks. The close-up on the right shows the so-called Talbot-carpet in the near-field. Pictures from Hornberger 2012, 159–160.

3 Interference as description of the relation between fields of knowledge

In his famous Rede-Lecture the writer and scientist Charles P. Snow stated that two cultures of cognition had developed in academia that neither wanted to nor could communicate with one another anymore. Frustrated, he notes to what little extent knowledge of nature is associated with culture:

A good many times I have been present at gatherings of people who, by the standards of the traditional culture, are thought highly educated and who have with considerable gusto been expressing their incredulity at the illiteracy of scientists. Once or twice I have been provoked and have asked the company how many of them could describe the Second Law of Thermodynamics. The response was cold: it was also negative. Yet I was asking something which is about the scientific equivalent of: Have you read a work of Shakespeare's?

I now believe that if I had asked an even simpler question – such as, 'What do you mean by mass, or acceleration,' which is the scientific equivalent of saying, 'Can you read?' – not more than one in ten of the highly educated would have felt that I was speaking the same language. So the great edifice of modern physics goes up, and the majority of the cleverest people in the western world have about as much insight into it as their neolithic ancestors would have had. (Snow 1964, 14–15)

Some forty years later, Alan Sokal's felicitous "hoax" with postmodernism (Sokal 2001) seems to show that the gap between these two cultures of knowledge is deeper than ever before. Sokal fooled a few prominent editors of a cultural studies journal by selling them physically untenable statements as justified by

cultural sciences. By this he showed that postmodernism in many cases abandoned scientific rigor for the coining of phrases. His conclusion, however, that this hoax sufficiently demonstrated that physics is an objective science solely guided by the constitution of nature and completely independent of the questions that society asks about this nature, is largely unfounded. This correlation cannot be derived scientifically since the questions are not related: Just as a wrong conclusion can be drawn from a correct argument, the conclusion drawn from an invalid argument might still be correct. The demonstration that there exists a reality that is not altered and influenced by our observation demands much more than a hoax article in the journal of sloppy postmodernists.

On the other hand, Snow and Sokal are of course right. Anyone who, for example, attends the early morning lecture at the physics institute of the University of Vienna and in the late afternoon a seminar on philosophy soon gets an idea about how different their styles of thought are. In the afternoon you meet people who work almost exclusively alone and focused on texts. The questions they think about are fundamental and concern the existence of the whole universe and the conditions of the possibility of its cognition. The knowledge developed here has to be free of contradictions and should form a systematically organized unity – even if the demand to create a closed system of thought has been abandoned in the twentieth century, methodological coherence usually still is required.

Before lunch, on the other hand, a collaborative work ethic dominates. Hardly anyone can cope with the demands of the physics courses and the practical work all on his or her own. The knowledge required here is as manifold as its applications. The collection of methods is thus somewhat eclectic and the physicists' models are only expected to describe the situation under discussion sufficiently. Not too many physicists are surprised if they agree only partially with one another. Generalizations from individual experience are treated with a certain caution.

In foundational research, the experiments are often surprisingly fragile and physicists spend most of their time repairing them. In comparison the texts and theories of the philosophers seem fairly robust and reality hardly ever bursts in. These differences in training, tacit knowledge and scientific culture are perpetuated by the current system of funding and publishing.

Interdisciplinarity has become a buzz word often required to open the doors to funding. However, while on paper fostering interdisciplinarity the funding agencies do in fact not know how to deal with such an approach. Their internal structure follows the very separation between the fields of knowledge that they claim to aim at overcoming. Interdisciplinary projects often result from cooperation between related fields, such as physics and chemistry. Honest advisors will

tell you that the chances of a grant application addressing both philosophy and physics are vanishingly small. One reason is the review process itself. Since the reviewers' background is usually limited to one discipline, they will understand only half of the proposal. I occasionally wonder why somebody agrees on reviewing an interdisciplinary proposal when being openly hostile to such approaches. The clash between fields of knowledge also have its roots in different traditions of publication. In most sciences what counts are short papers announcing the results of month and years of work. In the humanities on the other hand monographies are of much higher value. This lack of mutual appreciation of different ways of publishing blocks interdisciplinary career paths.

Stating these difficulties will, however, not help us much to understand the interaction of the different fields of knowledge. The concept of interference allows us to grasp this interaction, describing it as a superposition of two systems of knowledge.

To be honest, it was during my experimental work in quantum optics that I developed my understanding of the metaphor of interference. In our Kapitza-Dirac-Talbot-Lau interferometer for matter-waves, complex molecules enter a carefully prepared environment in which no information about their path can be obtained (Gerlich 2007). They do not behave as well-located particles anymore, but rather the motion of their center of mass can be described by a wave function. These matter-waves are diffracted at a grating, each wave passing at least two slits. Each opening in the mask acts as the source of a wave and the superposition of the emanating waves forms a complicated pattern. This interference pattern is recorded as evidence for the wave-like behavior of the molecules. Our setup shows that beyond mask and wave switching their roles as apparatus and object of the observation, even what forms the diffracted wave and what the diffracting element can be exchanged. Whereas in classical interference experiments light-waves are diffracted at material gratings, in the KDTLI a standing light-field acts as the diffraction mask which imprints a phase shift on the matter-wave (Kapitza 1933). Just as light and matter change their roles here, in the investigation of the interference of two fields of knowledge it should be possible to exchange their roles as diffracting and diffracted element. The cut that determines their roles depends on the question of the investigation.

At first glance it might seem that Luhmann's Systems Theory is able to justify such an approach and the introduction of the metaphor of interference is unnecessary. Betül Dilmac, for example, has used this theoretical approach in her published thesis on *Literatur und moderne Physik* (Dilmac 2012). According to Luhmann's theory, autonomous subsystems build up a total system where the environment of each subsystem consists of the other subsystems. The crucial difference, however, is that these systems are considered to be self-generating and

isolated, such that they interact only via communication: “The society as well as its partial systems are autopoietic systems whose operations are communications” (Dilmac 2012, 44).⁸

Each partial system has its specific form of communication, a characteristic code that only appears in this system. These codes are thought to be binary, and contain the fundamental operations which reproduce the system. Science for example operates with the code true and false whereas art uses the opposition of beautiful and ugly. A translation between the systems changes the code, such that writers are taken to be interested only in aesthetic aspects of science. This is insufficient to grasp Brecht’s metaphorization of Heisenberg’s microscope, which transfers a concept of truth from quantum physics to aesthetics. Ulrich Sautter postulates that Brecht does not try to connect science and art as two different disciplines but considers them both to be expressions of one and the same intellectual interest in cognition (Sautter 1995, 688). Brecht suspects that physics itself operates with aesthetic categories:

Today even an aesthetics of the exact sciences could be written. Galilei speaks about the elegance of certain formulas and the wit of experiments, Einstein ascribes a scientific function to the aesthetic sense and the atomic physicist R. Oppenheimer praises the “beauty of the scientific stance which is the most appropriate to the position of man on earth.”⁹

(Brecht 1967, Vol. 16, 662)

Brecht reports that the physicists themselves look for an aesthetic aspect in their work and he goes even further – the political revolt has its own elegance as well:

After Albert Einstein had read the latest paper written by Niels Bohr he exclaimed: “This is the highest musicality in the area of thought!” Equally well he could have said about the article: An uprising, well planned and powerfully conducted!¹⁰

(Brecht 1967, Vol. 20, 335)

8 Transl. by LM. “Die Gesellschaft genauso wie ihre einzelnen Teilsysteme sind autopoietische Systeme, deren Operationen Kommunikationen sind” (Dilmac 2012, 44).

9 Transl. by LM. “Es könnte ja heute sogar eine Ästhetik der exakten Wissenschaften geschrieben werden. Galilei schon spricht von der Eleganz bestimmter Formeln und dem Witz der Experimente, Einstein schreibt dem Schönheitssinn eine entdeckende Funktion zu, und der Atomphysiker R. Oppenheimer preist die wissenschaftliche Haltung, die ‘ihre Schönheit hat und der Stellung des Menschen auf Erden wohl angemessen scheint’” (Brecht 1967, Vol. 16, 662).

10 Transl. by LM. “Nach der Lektüre eines neuen physikalischen Aufsatzes von Niels Bohr rief Einstein: ‘Das ist höchste Musikalität auf dem Gebiet des Denkens!’ – Ebensogut hätte man von dem Aufsatz wohl sagen können: Ein Aufstand, schön geplant und mächtig durchgeführt!” (Brecht 1967, Vol. 20, 335).

The differentiation into binary codes seems to found the separation of the fields of knowledge which it tries to overcome. In contrast to Systems Theory, the historian of science Lorraine Daston proposes not only to investigate the relation between natural science and its cultural milieu but to approach science itself as culture (Daston 1998, 17), as science itself creates values and meaning and does not simply borrow them from other spheres which are considered to be cultural (Daston 1998, 29).

With the concept of blending, literary studies offer an interesting approach to a description of the interaction of two such cultures, of what is going on between Brecht and quantum physics. Blending describes cognitive processes that integrate two discrete and clearly distinct concepts (Fauconnier and Turner 1998). It generally operates with the metaphor of space and the relations between logical sets are translated into relations between spaces. The two or more input sets are called input spaces, in our case the measurement problem of quantum physics and the role of the audience in the epic theater. The set of all common features is the generic space, for example the similarities of the entities they operate with and the influence of the observation on the observed process. In the blended space parts of the generic space, and input from the outside world, such as the common historic background that Quantum Physics and Epic Theater share, come together and form a new “emergent structure” (Fauconnier and Turner 1998, 135), which cannot be dissolved into the structure of the input spaces. Here we find a metaphor of cognition and truth in which physics and theater “fuse” (Fauconnier and Turner 1998, 141) in the (artificial) historic setting of two emigrants discussing the world economic crisis.

But the metaphor of Heisenberg’s microscope contains an epistemic stance that leaves neither input space untouched. It feeds back and alters them. The measurement problem in quantum physics shakes the very foundations of classical physics, it demands that we rethink notions that lay at its core: causality, time and trajectory, to mention the most important. In Brecht’s theater the active role of the audience clashes with the Aristotelian approach that postulates catharsis as the aim of all drama. A completely new style of acting had to be developed and the way the story is told changed dramatically, paving the way for modern postdramatic theater (Lehmann 2008). In blending theory this feedback is described as projection or mapping back from the blend to the input spaces. This projection can change the input spaces by altering their properties and adding new ones. This in turn will change the generic space from which the blend feeds. Together the input spaces, the generic space, the blends and the frame of background knowledge form a “conceptual integration network.” The relations between elements of each set are described as the topology of the respective space. A blend will work well if the relations between the projected

elements are maintained, that is if the topologies of the blend and one or all of the input spaces agree (Fauconnier and Turner 1998, 163).

If the back-action of the blend on the input spaces is somewhat random, it wouldn't be surprising if after some time the common set vanishes, the generic space becomes empty and the blend is exhausted. In physics, a necessary condition for the evolution of interference fringes is the coherence of the interfering waves, which means that their phase relation is maintained during their propagation. In the description of the interaction of fields of knowledge, coherence can be described such that the back-actions of the blended space on the input spaces alters the input-spaces in a way that maintains the agreement of the topology of inputs and blend. As the interaction continues, the blended space and input spaces so to speak *resonate*. This can constitute a dynamic system that lasts for a certain number of feedback-loops – that is it lasts for a certain time which we might call its coherence time, if we dare to extend the metaphor even further.

Unlike the concepts of reflection and representation, the notion of interference allows us to avoid the production of analogies and homologies. These concepts apply to a comparison between separated notions. In an interference we do not reflect something existing by something else that exists for itself – from an interference an entity evolves in which both interfering moments enter. In order to observe it, we have to discontinue the development of this entity and its state has to be projected and fixed. Depending on where this cut is made, certain aspects of the entity will become visible by leaving traces on the screen, which we can follow (Barad 2007, 164). We might set the cut such that one of the fields of knowledge appears to be the diffraction mask and the other the scattered wave. This allows us to read off the influence of the diffracting element on the scattered system from the interference pattern.

Different cuts will produce different pictures of this interference, the coherent interaction of two or more input spaces. In the case of Bertolt Brecht's theater and quantum physics, the coherence is founded on their common social, historical and cultural environment, and the shared set of notions, methods and problems that it offered.

Both epic theater and quantum physics evolved in the Weimar republic and were shaped by the exile during National Socialism into which not only Brecht but also many physicists were forced. Brecht's *Life of Galilei*, which has at its core the social responsibility of the physicist, was written and rewritten during this exile and is intimately intertwined with Brecht's engagement with physics. When he took up work on this drama during his Danish exile, Brecht sought the advice of Niels Bohr and though the Nobel Prize laureate did not find much

time, his assistants supported Brecht (Bunge 1985, 98). In Los Angeles, the last station of his exile, Brecht radically revised the drama, while a few hundred kilometers away the first atomic bombs were built (Mairhofer 2010). In his American exile Brecht's work was stalled and he saw no chance of staging his plays. In this situation he started a discussion with the philosopher and physicist Hans Reichenbach on the problem of causality in quantum physics. The debate somewhat escalated after a lecture that Reichenbach held at UCLA, and which not only Brecht attended, but also Adorno and Horkheimer. The proponents of the Frankfurt School vehemently opposed Reichenbach, who saw neither a need nor a justification for the notion of a strict causality in physics. In Reichenbach's view, physicists appear as "gamblers" whose predictions are just a "best bet" on the result of the experiment. The figure of thought of the gambler reappears in Brecht's last important drama, the *Caucasian Chalk Circle*. The drama has the same causal structure as an experiment in Quantum Physics. The figure of thought of the gambler is intimately connected with a new ethics. In the structure of the play as well as in the formation of its scenes and characters, the concept of game plays a central role. I have described the impact of both the problem of observation and causality in Quantum Physics on the *Caucasian Chalk Circle* (see Mairhofer 2013).

This long-lasting conversation between two such different fields of knowledge as physics and theater was fostered by a common set of notions. As examples, consider the concept of the field, which Faraday and Maxwell transferred from farms and war into physics, where they used it to describe the electric and magnetic interactions between physical objects as entities in their own right, and having the same ontological status as the objects themselves, acting back on their own sources (Maxwell 1954, ix). *Gestalttheorie* emphasized the priority of the relation over the relata and applied not just the terminology but also the mathematical formalism and methods of graphical representation of the field concept developed in physics to psychology and sociology (Köhler 1971, Lewin 1939). Brecht uses the notion of the field to describe how the meaning of a sentence always depends on the network of sentences in which it is uttered. He also applies the notion of the field when he demands that characters should develop during the plot, according to their mutual and dynamic relations. These relations he often frames as collectives, introducing with this term a level between the isolated individual and the abstract mass. Interestingly, this politically charged term was transferred to quantum mechanics by Soviet-Russian physicists to describe phenomena in solid state physics that result from the motion of many particles. The concept of the collective developed into an important tool and finds wide application in physics (Kojevnikov 2012).

This brief outline of the reasons for the coherence of epic theater and quantum physics also demonstrates that many different cuts are possible, and that these cuts will exhibit different features of the interfering entities. The metaphor of interference thus allows us to embrace different representations of the same interaction. Different methodological approaches to one and the same object under investigation can be understood as complementing instead of competing with one another. The historian of science shows us the shared concepts with which epic theater and quantum physics operate. An investigation of the social, cultural and historical background reveals that these notions were developed as responses to shared biographical situations. Traces of this interaction can be found in forgotten manuscripts in the archive that contains the material of Brecht's friend Hans Reichenbach (see for example Brecht 1973, 387 and document number 040-02-09 of the archive). A more discourse-oriented approach discovers shared figures of thought, such as the gambler for quantum physics, Brecht's ethics and in philosophical anthropology (Mairhofer 2013). Finally, a close reading of Brecht's *Caucasian Chalk Circle* demonstrates the influence of quantum physics with regard to the constitution of the characters, the structure of the play and the dominant role of chance in the plot.

It seems to me to be a necessary condition for this process of interference of two fields of knowledge, that the basic entities and their relations, with which the two fields operate, can be translated into one another. For this they have to maintain a similar *Gestalt* and function (where the similarity is more constant than the changing *Gestalten*). The fundamental entities of physics underwent a profound revolution in quantum physics just as the fundamental entities of society did in Brecht's epic theater. The indivisibility of the atom and the individual were both radically questioned. Nevertheless these two fields of knowledge kept blending. In this sense I think we can speak of a coherence between the atom in quantum physics and the individual in epic theater.

In an article with quite some impact on the research on Bertolt Brecht, Hans-Thies Lehmann and Helmut Lethen discuss three sources of Brecht's critique of the idealistic fiction of the subject (Lethen 1980, 157). Marx describes the individual as the ensemble of contradictory social relations. According to Freud's concept, the individual evolves in the intersection of antagonistic mental instances; and Nietzsche finally locates the individual in the tension between body and mind. I would suggest adding quantum mechanics to these sources, insofar as the fundamental entities with which epic theater and quantum physics operate show a strong coherence. Quantum mechanics challenges not only the particle character of atoms, but also the continuity of atomic processes, their strict causality and their *Anschaulichkeit*, a term that is not readily translated into English but expresses the idea that a fact is intuitively accessible

because it is directly represented by sense impressions (Kojevnikov 2011). In his *Verfremdungseffekt*, Brecht repeatedly disrupts the plot in order to open up the gap between representation and object. He tries to avoid a theater that is *anschaulich* and wants to make the audience think about different possible progressions of the story, thus calling into question the strict causality of the events. Finally, the continuous existence of the fundamental entities itself is questioned, as function becomes more important than essence.

Classical physics is founded on the existence of indivisible atoms which exist prior to any interaction and whose dynamics is then described. Gideon Freudenthal shows how synchronously with the conception of the Newtonian atom the notion of the individual develops and takes its crucial role in the bourgeois theory of the social contract (Freudenthal 1982, 265–270). Both classical mechanics and bourgeois social theory are founded on the assumption that the properties of the fundamental entities are independent of their relations (Freudenthal 1982, 160–161). The First World War proved this assumption of free subjects existing prior to all society to be an “idealistic valorization of the individual” (Lethen 1980, 157).¹¹ Brecht notes: “War shows the role that the individual is meant to play in the future. The individual as such achieves an intervening effect only as it represents many” (Brecht 1988–2000, Vol. 21, 436).¹²

The new conception of the fundamental entities in both physics and society that developed during the Copernican Revolution is intertwined with an epistemological revolution. In Aristotelian physics only one privileged point of view allows us to correctly describe physical processes: the earth that is thought to rest at the center of the universe. By contrast, in Newton’s theory many reference frames allow for a correct description, the inertial systems. Which phenomena correspond to a certain event now depends on the point of view of the observer. But the different observations can be translated into one another. In Newtonian physics, however, this requires the existence of an absolute space, which again distinguishes a certain stance that allows for this translation. Remarkably, Newton develops this theory during the Glorious Revolution, which ends with the proclamation of a constitutional monarchy, where in Parliament different points of view are balanced while the king or queen still occupies the distinguished position of an absolute stance. (Wo)man has been removed from the center of the universe and has been put in the center of its cognition (Blumenberg 2010, 107). In quantum physics this epistemic position is shaken to its

¹¹ Transl. by LM. “idealistische Valorisierung des Individuums” (Lethen 1980, 157).

¹² Transl. by LM. “Der Krieg zeigt die Rolle, die dem Individuum in Zukunft zu spielen bestimmt war. Der einzelne als solcher erreichte eingreifende Wirkung nur als Repräsentant vieler” (Brecht 1988–2000, Vol. 21, 436).

very foundations. This again is intertwined with a reconceptualization of basic entities. As early as 1926, when the first mathematical formulations of quantum mechanics had just been found, Brecht compared the figures of his plays with the entities of modern physics:

Even if one of my persons moves in contradictions, this is only because (wo)man in two different moments is never the same. [...] The continuous subject is a myth. (Wo)man is an ever-fragmenting and recomposing atom.¹³ (Guillemin 1975, 198)

This echoes the radical critique formulated by the Viennese physicist and historian of science Ernst Mach, who only accepts the existence of sense data. Mach takes it as the main task of science to give an economical description of the sequences of impressions of our senses, and denies any possibility of a representation of the objects themselves. He opposes any “metaphysical” speculation that exceeds a description of our sense data (Janik 1973, 134). Thus he opposes the assumption of the existence of fundamental entities on the part of the object as well as on the part of the subject. Mach “trashes” [zertrümmert] (Brecht) the atom as well as the individual.

This approach found much less resonance among physicists than among historians of science. Although they agree with Mach’s critique of metaphysical interpretations of physics, Ludwig Boltzmann and Heinrich Hertz oppose the refutation of the existence of both moments of observation, the subject and the object. Hertz takes physical theories to be models, in which abstract notions are connected to reality by experimental procedures. In Mach’s concept we passively contemplate our sense data while in Hertz’ approach we actively produce this sense data (Janik 1973, 140). While Mach sets an external limitation on the validity of physical theories by the prohibition of metaphysics, the validity of a model is inherently given by its structure (Janik 1973, 145–146).

Brecht embraces the approach of Hertz and Boltzmann rather than the critique of Mach. He develops a series of models of the constitution of the individual in its contradictory relations. These models are tested on the theater’s stage, where the figures build up in the course of the plot rather than being presupposed by it. Niels Bohr on the other hand describes how the properties of the basic physical entities build up in the relations into which they enter in the experiment. He refuses to designate them as particles or waves but instead calls

13 Transl. by LM. “Auch wenn sich eine meiner Personen in Widersprüchen bewegt, so nur darum, weil der Mensch in zwei ungleichen Augenblicken niemals der gleiche sein kann. [...] Das kontinuierliche Ich ist eine Mythe. Der Mensch ist ein immerwährend zerfallendes und neu sich bildendes Atom” (Guillemin 1975, 198).

them “individuals” (Bohr 1961, 59). Individual as well as atom in his thought are highly precarious:

In particular, the apparent contrast between the continuous onward flow of associative thinking and the preservation of the unity of the personality exhibits a suggestive analogy with the relation between the wave description of the motions of material particles, governed by the superposition principle, and their indestructible individuality.

(Bohr 1961, 99–100)

While Brecht does not develop one single coherent concept of the individual, the quantum physicists put forward manifold interpretations of their mathematical formalism and the corresponding experiments. In both fields of knowledge the observers influence the observed process, and its representation in a formal system becomes ambiguous. The continuity of the processes and the distinguishability and thus the individuality of the fundamental entities partaking in these processes is suspended.

The possible interactions among entities are altered along with the entities themselves. Entities no longer enter into their relations with predefined properties but rather constitute themselves in these relations. The determination of the fundamental entities is intimately connected to the determination of their causal relations, as it is these relations that define an entity. It might well be that the entity is even constituted in these relations. Then the epistemic relation between observer and object also becomes precarious, as the object can no longer be perceived objectively, which is expressed in the metaphor of Heisenberg’s microscope.

A shift in the understanding of the category “entity” or “unity” [Einheit] (Kant 1968, 118 (B106)) with which a style of thought operates will necessarily change the style of thought as a whole. The category “entity” proves to be the *a priori* form of cognition postulated by Kant. This *a priori*, however, can no longer be understood in his sense as ahistorical and purely logical, as cognition is not unidirectional but relies on a feedback between knowledge and object. This feedback is achieved through the application of the model to reality; that is, in the practice that results from our insights and is directed at the object. The result of this practice again alters our knowledge.

To conclude, the concept of interference allows us to describe the interaction of fields of knowledge and to describe the necessary conditions for this interaction, the coherence of the basic entities with which these fields operate. This interference is best represented not by a single fringe pattern but by multiple projections that are produced and investigated using a wide range of methods.

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