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The Conserved Quantity Theory of Causation and Chance Raising

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In this paper I offer an 'integrating account' of singular causation, where the term 'integrating' refers to the following program for analysing causation. There are two intuitions about causation, both of which face serious counterexamples when used as the basis for an analysis of causation. The 'process' intuition, which says that causes and effects are linked by concrete processes, runs into trouble with cases of 'misconnections', where an event which serves to prevent another fails to do so on a particular occasion and yet the two events are linked by causal processes. The chance raising intuition, according to which causes raise the chance of their effects, easily accounts for misconnections but faces the problem of chance lowering causes, a problem easily accounted for by the process approach. The integrating program attempts to provide an analysis of singular causation by synthesising the two insights, so as to solve both problems.

In this paper I show that extant versions of the integrating program due to Eells, Lewis, and Menzies fail to account for the chance-lowering counterexample. I offer a new diagnosis of the chance lowering case, and use that as a basis for an integrating account of causation which does solve both cases. In doing so, I accept various assumptions of the integrating program, in particular that there are no other problems with these two approaches. As an example of the process account, I focus on the recent CQ theory of Wesley Salmon (1997).

1. The Conserved Quantity Theory and the Problem of Misconnections. The conserved quantity theory has been offered in a number of forms (see Dowe 1992, 1995, 1998; Salmon 1994, 1997; and Skyrms 1980). We will consider just the most recent version formulated by Wesley Salmon (1997), although the problem to be considered is a problem for

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all the versions just mentioned. According to Salmon the following three definitions capture the essence of causality:

> Definition 1: A causal interaction is an intersection of world-lines that involves exchange of a conserved quantity,
>
> Definition 2: A causal process is the world-line of an object that transmits a non-zero amount of a conserved quantity at each moment of its history (each spacetime point of its trajectory),
>
> Definition 3: A process transmits a conserved quantity between A and B (A≠B) if and only if it possess [a fixed amount of] this quantity at A and at B and at every stage of the process between A and B without any interactions in the open interval (A,B) that involve an exchange of that particular conserved quantity. (Salmon 1997, §6, 2)

This theory has been refined over recent years in response to various criticisms and problems (see references listed above). However, if we wish to apply the theory to the question of how the events or facts that we call causes and effects are connected, clearly more work is needed.

This is highlighted by the well known fact that the conserved quantity theory has problems with what I will call 'misconnections'; where two events or facts connected by causal processes nevertheless are either causally irrelevant to one another; or negatively relevant, i.e. where one tends to prevent the other. One example of the latter is Cartwright's (1983, Ch. 1) sprayed plant: a healthy plant is sprayed with a weedkiller which kills nine out of ten plants, but this particular plant survives. We can provide a set of causal processes and interactions (characterized by the transmission of conserved quantities) linking the spraying and the surviving, yet spraying does *not* cause the plant's survival. Papineau (1989, 1986) has given a similar case: being a fat child does not cause one to become a thin adult, although causal processes link the two. As in the sprayed plant case, two events which we would not call cause and effect are linked by a set of causal processes and interactions.

In fact it can be shown that the failure of the conserved quantity theory at this point is *more* widespread and general than has been recognized. These counterexamples are not esoteric quibbles but a commonplace feature of causation. Consider a tennis ball bouncing off a brick wall, a paradigm case for the conserved quantity theory, since it involves clear cut cases of causal processes and their interaction. The passage of the ball through spacetime is a causal process by definitions 2 and 3 since it possesses a conserved quantity (momentum) at each instant of its history. The collision between the ball and the wall is a causal interaction by definition 1, since the momentum of the ball changes at the intersection of their worldlines. Yet, while its hitting the wall is the cause of its rebounding, nevertheless the collision with the tennis ball does not cause the wall to remain in the same place, nor does it cause the wall to be still standing. Nor does the collision cause the ball to still be green and furry.

For any causal schema involving genuine causal processes and interactions there will be numerous events, facts, or states of affairs which are part of the schema. There is no guarantee that any two such events or facts will stand in a causal relation: in general they will not (the misconnections), although some will. Thus spraying the plant with weedkiller does not cause it to survive, nor to still have mostly green leaves, nor to still be in the corner of the yard; while spraying does cause it to be less healthy and to have some slightly yellowed leaves (let's say).

Indeed, these considerations raise the suspicion that the conserved quantity theory fails to provide a sufficient condition for singular causation relative to *every* actual schema of processes and interactions. If this is so then the conserved quantity theory is hardly an adequate account of the way causes and effects are connected.

Can the conserved quantity theory be developed so as to overcome this difficulty? Well, it is clear that more needs to be said about the events or facts which are linked by causal processes and interactions, and how they are thereby linked.

We shall suppose that the causal relata are either events or facts, both of which concern objects having properties at a time or a time period. Suppose an *event* is a change in a quantitative property of an object at a time; and a *fact* is an object having a quantitative property at a time or over a time period. Because both events and facts reduce to objects and quantities, this fits well with the conserved quantity theory. For simplicity, let's deal just with facts. Then, presumably, according to the conserved quantity account two facts are connected in a causal relation if and only if there is a continuous line of causal processes and interactions between the objects involved in those facts at those times.

Furthermore, we will take it that such facts or events, if they enter into causation, must involve conserved quantities or supervene on facts and events involving conserved quantities. For example, the fact that the ball is green must supervene on the fact that various bits of the surface of the ball's fur have certain physical properties in virtue of which the ball looks green. If these properties are not conserved quantities, then they in turn must supervene on conserved quantities. This seems to be a natural development of the conserved quantity theory. Then we can write the relevant fact as $q(a)=x$, which reads 'object a has x amount of conserved quantity q'. If a second type of conserved quantity is involved, we will write this as 'q''.

Then for the most general case of cause and effect we can write the cause as q(a) and the effect as q′(b), where a and b are objects and q and q′ are conserved quantities possessed by those objects respectively, at the appropriate times. Then we can take it that:

> Definition 4: Fact q(a) and a fact q′(b) are related as cause and effect if and only if there is a thread of facts between q(a) and q′(b) such that:
>
> (1) at every point on the thread there is an object which possesses a conserved quantity, such that any change of object from a to b and any change of conserved quantity q to q′ occur at a causal interaction involving the following changes: Δq(a), Δq(b), Δq′(a), and Δq′(a); and
>
> (2) for any exchange in (1) involving more than one conserved quantity, the changes in quantities are governed by a single law of nature.

The purpose of (2) is to rule out cases where independent interactions occur by accident at the same time and place.

For example, to take a simple case, the earlier momentum of a billiard ball (q(a) at t_1) is responsible in the circumstances for the later momentum of the same ball (q(a) at t_2). Then the cause-fact and the effect-fact are linked by a single thread involving just the object a and the quantity q, momentum.

As a second example, shown in Figure 1, suppose the ball collides with another, so that the earlier momentum of the first ball (q(a) at t_1)

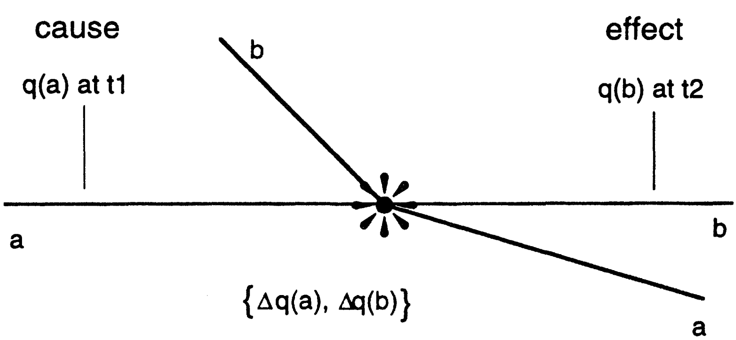

Figure 1. Collision between two balls, a, b. That the first had a certain momentum q(a) is the cause of the fact that the momentum of the second was q(b).

is causally responsible for the later momentum of the second ball (q(b) at t_2). Then the cause and the effect are linked by the thread involving firstly q(a), the first ball having a certain momentum; then the interaction Δq(a), Δq(b), the exchange of momentum in the collision, and then q(b), the second ball having a certain momentum. There is a change of object along this thread, but no change in the conserved quantity.

As a third example, suppose (in a fictional physics) an unstable atom is bombarded by a photon of absorption frequency, which leads to the subsequent decay of the atom (Figure 2). Take q to be energy and q′ to be charge. Then the cause q(a), that there is an incident photon with certain energy, is linked to the effect q′(c), that the second atom exists as the product of the decay. It is linked by a thread involving one interaction where there is an exchange of energy, and a different object, and a second interaction where one object becomes another, with an exchange of charge and of energy, which leads to the effect object having a certain charge, in virtue of which it is called the decay product. Further, there are laws governing how energy changes in a such a decay, involving the change in charge that it does.

Suppose, to vary the example, that the atom happens not to decay. Then, by the present account, the incident photon is not the cause of the fact that the atom did not decay, since the effect concerns charge, not energy, and there is no interaction where both energy and charge are exchanged.

We can now see how to deal with cases such as the tennis ball's momentum causes it to be green. This is ruled out because there is no appropriate thread involving an object and a conserved quantity. There is the continued existence of the ball and its momentum, but that does not belong to the same thread as the existence of green fur.

This may also solve the sprayed plant case, if for example the cells affected by the poison simply die and the plant's continued life is the result of the development of other independent cells.

However, while it solves many of these sorts of counterexamples, this account cannot completely solve the problem of misconnections. Suppose, to give a fairly abstract example, that some object has quantity $q = 50$, and that a critical value of q for the object is 45 (below which it decays or is dead or something). Suppose an interaction occurs which raises the value of q by 20, then a second interaction occurs which lowers the value of q by 40, leaving it with a q-value of 30, below the critical value. Define the following events (see Figure 3):

f_1 — q's value is raised by 20 at t_1
f_2 — q's value is lowered by 30 at t_2

f_3 — q's value is 40 at t_3
f_4 — q's value is less than 45 at t_3

Now, we might be happy to say that f_1 caused f_3, because without f_1 the object would have had a lower value of q (although this would be debatable). But we would not, by any stretch of the imagination, say that f_1 caused f_4. For a start, without f_1 f_4 would have been much more likely. But the problem is, on the embellished conserved quantity account, f_1 *does* cause f_4 because it is the same object and the same quantity involved in both events, connected by a single causal thread.

A concrete example of this would be where, in a cold place, the heater is turned on for an hour, bringing the room to a bearable temperature. But subsequently someone opens the window, and the tem-

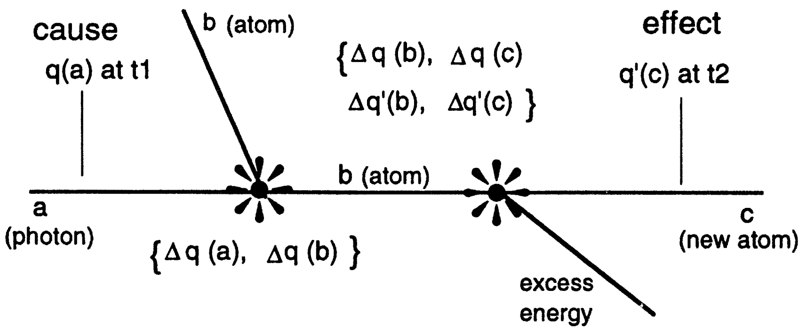

Figure 2. Incident photon a strikes atom b, raises its energy level, which then decays to atom c.

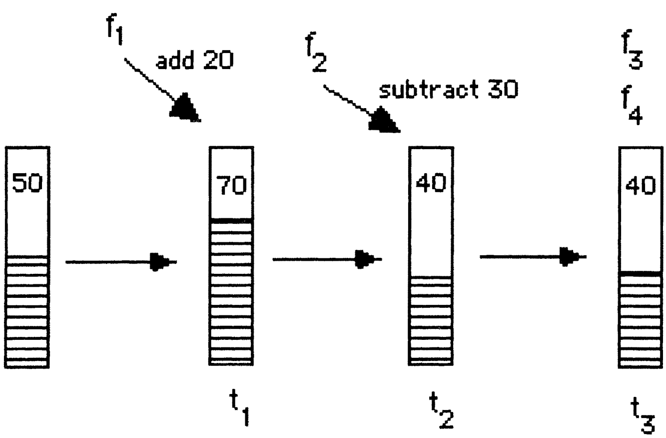

Figure 3. Misconnections.

perature drops to, say, 2° C. Then on the CQ account the fact that the heater was turned on is the cause of the fact that the temperature is unbearable at the later time.

It seems to me that this captures the basic difficulty behind cases such as the sprayed plant and the fat child: two facts are linked by causal processes and interactions, yet one lowers the chance of the other. To bite the bullet here would be to accept the implication that f_1 caused f_4, and insist that whenever two facts are appropriately linked they are causally related. This may have the implication that there is no such thing as unsuccessfully inhibiting something, since a case like the sprayed plant is a case of causal connection. This certainly is counterintuitive, to say the least.

Cartwright's and Papineau's examples were intended to show that an alternative tradition—namely the probabilistic or chance raising account of causation—is able to account for these cases. We now turn to that theory.

2. Chance Raising Theories and Chance Lowering Causes. The probabilistic or chance raising theory of causation takes causation to hold between two events only if the occurrence of one event, the cause, makes the probability of the other, the effect, much greater than it would otherwise be.[1] This condition is typically conjoined with others, for example, that the cause occur before the effect, and that there is no third event which "screens off" the relevant relation. We shall consider the probabilistic theory only in so far as it is a theory of singular causation; that is, of the particular relation in virtue of which two particular events or facts are cause and effect.

It is usually held that the chance raising theory easily handles the problem of misconnections, and for the purposes of this paper we will grant that. Being sprayed by defoliant doesn't raise the probability of the plant surviving—it lowers it; being a fat child doesn't raise the probability of being a thin adult, and turning on the heater doesn't raise the probability that the room would be an unbearable temperature shortly after. The tennis ball hitting the wall doesn't raise the probability of the wall staying standing in the same place, or of the ball being green and furry.

1. In philosophy this sort of theory is usually traced to Suppes' influential book *A Probabilistic Theory of Causality* (1970), (see also Suppes 1984, Ch. 3), although both Reichenbach and Good had offered earlier versions. See Good 1961, 1962; Reichenbach 1991. See also Cartwright 1983, Eells 1991, Glymour et al. 1982, Lewis 1986, Humphreys 1989, and Mellor 1995.

However, one persistent argument against the probabilistic or chance raising theory concerns counterexamples where a particular causal chain contains elements which lower the chance of their effect.[2] One example, given by Eells and Sober (1983), is the case where a golf ball is rolling towards the cup, but is kicked by a squirrel, and then after a series of unlikely collisions with nearby trees, ends up rolling into the cup. This is a case, it is argued, where a singular cause lowers the probability of its effect, in other words, a counterexample to the claim that the probabilistic theory provides a necessary condition for singular causation.

There are a range of ways to handle cases like these.[3] However, these methods cannot handle certain cases involving the kind of genuine single case objective chance found in quantum mechanics. Consider the following example (see Figure 4), which, according to our best physical theories, involves genuine indeterminism.

An unstable atom Pb^{210} may decay by various paths as shown in Figure 4, which depicts the complete range of physical possibilities for this atom. Pb^{210} may decay to either Po^{210} or to Tl^{206}, in each case by a two step process. When Pb^{210} decays, the probability that it will produce Hg^{206} is 1.8×10^{-8}. The probability that Hg^{206} will produce Tl^{206} is one. When Bi^{210} decays, the probability that it will produce Tl^{206} is 5.0×10^{-7} (from Enge 1966, 225, via Dowe 1993[4]). We assume that each unstable atom has a very short half-life relative to the time frame under consideration.

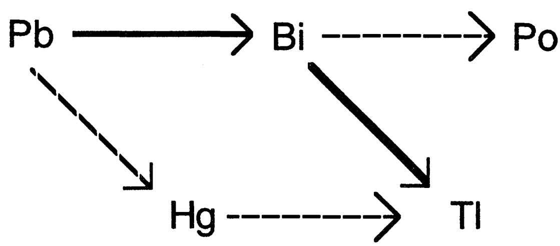

Figure 4. Chance-lowering decay scheme.

2. Such counterexamples are variations on an example due originally to Rosen (1978).

3. Salmon (1984, Ch. 7) has outlined a number of methods used to solve this type of problem; see also Glymour et al. 1982. Another kind of strategy is the 'despite defence' suggested by Suppes (1984, 67) and defended by Papineau (1989, 1986), Eells (1988, 130) and Mellor (1995, 67–68). I have addressed this in length elsewhere (Dowe 1996, 1993) and will not consider it here.

4. In turn a variant of a case presented by Salmon (1984, 200–201). See also Dowe et al. 1996.

Let C be the decay to Bi; D the decay to Hg; E the production of Tl; F the production of Po. Note that these events are not time-indexed. Then,

$$\begin{aligned} P(E) &= P(C)P(E|C) + P(D)P(E|D) \\ &= [(1 - 1.8 \times 10 - 8) \times 5.0 \times 10 - 7] \\ &\quad + (1.8 \times 10 - 8 \times 1) \\ &= 5.18 \times 10^{-7} \\ \text{and } P(E|C) &= 5.0 \times 10^{-7} \end{aligned}$$

Thus C lowers the probability of E.

Take a particular instance (Figure 5) where the process moves: Pb^{210}, Bi^{210}, Tl^{206}, i.e., C occurs and leads to E. Then we should say that C causes E, yet it lowers its chance.

Classic versions of chance raising theory, such as Suppes 1970, fail to account for this case. Suppes requires that $P(E|C) > P(E)$ unless there is some other factor which screens off this dependence. In our case there isn't, since it is genuinely indeterministic (Dowe 1993, Salmon 1984). Other versions require that $P(E|C) > P(E|-C)$, which also fails in our case since $P(E|-C) = 1$.

One influential variation of the chance raising theory is the probabilistic dependence theory of David Lewis (1986, 175–178), which replaces the conditional probability relation with 'probabilistic dependence'—a counterfactual conditional about chance of the form 'if event C were to occur, the chance of event E would be much greater than if C were not to occur.' Lewis' theory has a number of advantages over the usual probabilistic theory; however it too fails to account for the decay case. For if C were *not* to occur (that is, if the decay Pb→Bi were not to occur) then E would be more likely than if C did occur, because C's not occurring leaves a state of affairs such that Pb atom has not decayed, but will soon, ensuring that D occurs and subsequently, with probability 1, that E occurs.

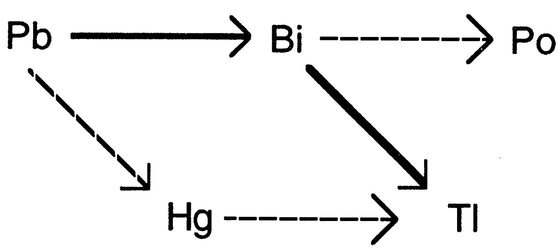

Figure 5. Chance lowering cause.

A recent version of the counterfactual approach is that of Mellor (1995), who takes the chance of an effect to be a fact about the cause in its circumstances, such that for C to cause E the chance that C gives E must be greater than the chance of E in the same circumstances but without C,

$$ch_{C}(E) > ch_{\sim C}(E).$$

where the value of $ch_{\sim C}(E)$ is given by the closest world conditional $\sim C \Rightarrow ch(E) = p$; and the chances are understood as single case objective chance. However, this also fails in the decay case, since $ch_C(E) = 5.0 \times 10^{-7}$, while ch(E) at closest ~C-worlds is about 1.

However, the conserved quantity theory provides a ready answer to this kind of counterexample. Take the squirrel case, where a golf ball is travelling towards the hole, and a squirrel kicks the ball away, but (improbably) the ball hits a tree and goes in. There is a single thread of causal processes and interactions, all involving the ball, which can be traced from the squirrel's kick to the ball's landing in the hole. The kick is a genuine causal interaction, and so is the collision with the tree (both are changes in the momentum of the ball). The same may be said for the decay case. An atom is a genuine causal process and its decay is a genuine causal interaction involving, as it happens, not only production of the atom Tl, but also either an alpha particle or a beta particle. Both C and E, in our particular case, involve a change in charge, a conserved quantity. Thus the conserved quantity theory accounts easily for these counterexamples. Not surprisingly, this has been one of the major arguments in its favor.[5]

So we have two theories and two problems. The probabilistic theory cannot handle the chance lowering causes, but easily handles the misconnections. The process theory easily handles the chance lowering cases, but cannot handle the cases of misconnection. This suggests an approach which incorporates both of these insights. In the next section we turn, therefore, to 'integrating' solutions.

3. Integrating Solutions. Some philosophers have responded to this situation by positing an approach which combines the process and the chance raising intuitions. I call such a synthesis an 'integrating solution.' However, the two requirements we have considered cannot simply be conjoined. Since the chance raising requirement is not a necessary condition for singular causation, the conjunction of the two is also not a necessary condition.

5. For example, Dowe 1996, 1993; also Salmon 1984, Ch. 7.

Some authors (Sober (1985) was perhaps the first) have pointed to an asymmetry between the case of the squirrel (and the decay case) and the case of the sprayed plant. The asymmetry is that while both have the same probabilistic structure, with the particular events occurring contrary to the governing statistical relations, yet the squirrel's kick is a cause and the spraying of the plant is not. Some authors have used an explanation of this asymmetry as the basis for an account which brings together both the chance raising insight and the process insight. Authors who have attempted such a synthesis include Eells, Lewis, and Menzies.

In *Probabilistic Causality*, Ellery Eells suggests (1991, Ch. 6; see also 1988) that the difference between cases like the decay case and the sprayed plant is due to the different ways that the probability of an effect evolves between the occurrence of the two events. C causes E just if P(E) changes at the time of C, and is high just after C, higher in fact than it was just before C, and remains high until the time of E (see Eells 1988, 120). This gives the right result for cases like the sprayed plant, but it does not solve the decay counterexample. The particular instance where the decay process moves from Pb → Bi → Tl gives a trajectory for P(E) which drops at C *and remains lower*, yet we call C a cause of E. More specifically, the probability trajectory develops as follows: up until and immediately before C the probability of E is 5.18×10^{-7}, and from C until immediately before E the probability of E is 5.0×10^{-7} (see Dowe 1996, 230–231).

A more promising approach is due to Lewis and Menzies. Lewis (1986, 175–184), defines a 'chain of probabilistic dependences' (in Menzies' wording (1989, 650), as an ordered sequence of events such that each event probabilistically depends on the previous event. I (1996, 232) call this a 'Lewis-chain'. Then C is a cause of E if and only if there is a Lewis-chain between C and E.

According to Menzies (1989) there is an *unbroken causal process* between events C and E if and only if for any finite sequence of times between C and E, there is a corresponding sequence of events which constitutes a Lewis chain (of probabilistic dependences), and C is a cause of E if and only if there is a chain of unbroken causal processes between C and E. I (1996, 232) call this the 'Menzies-chain'. The effect of this is to allow one to cut the chain at convenient places.

These accounts are able to handle the decay case as set out above. Take the event C′, the existence of the Bi atom at a time between the occurrences of C and E. There is a relation of probabilistic dependence between C and C′ because if C were not to occur then C′ would not occur, except in the unlikely scenario that a Bi atom is produced by a process other than the decay of that Pb atom. Thus if C were not to occur, C′ would be very much less likely than if C were to occur. There is also a relation of probabilistic dependence between C′ and E because if C′ were not to occur then E would almost certainly not occur. (This follows from the Lewis approach to interpreting these counterfactuals: in supposing C′ not to occur, we hold fixed the world up until the time of C′, which means that C occurred (and so the decay to Hg will not), and that the atom Bi has disappeared; so there's virtually no chance that E will occur.) Thus there is a Lewis chain linking the cause and the effect, comprising of C-C′-E. There is also a Menzies chain. For any time t_i between the times of C and E one can define the event C_i, the existence of the Bi atom at time t_i, such that C-C_i-E forms a Menzies chain (see Dowe 1996, 232).

However, these theories are not successful with a simple hypothetical variation on the decay case (see Dowe 1996, 232–233; Salmon 1984, Ch. 7) where we have a *cascade*, where the Bi atom immediately decays to Tl (supposing that time is discrete, and that the decay of Bi to Tl occurs at the very next instant following the decay of Pb to Bi). Then there is no time between the times of C and E, and so there is no event C′, and since C and E do not stand in the relation of probabilistic dependence, there is no Lewis chain between the cause and the effect. And by similar reasoning, there is no Menzies chain between the cause and the effect. This counterexample brings out the fact that there is something ad hoc about this kind of solution. It shouldn't matter how dense the process is linking cause and effect.

So these attempts to incorporate the idea of a process into a chance raising theory seem to fail to account for the decay case. However, I think that an alternative approach can succeed where these fail. This account turns on a new diagnosis of chance lowering causes.

4. Diagnosis: Mixed Paths. The integrating account considered in the previous section all veered closer to the chance raising account than to the CQ theory. It is not surprising, therefore, that they handle the misconnections case but not the chance lowering causes. This suggests that what we need is an integrating theory which takes the notion of a process more seriously. The first step in this account is to recognize the difference between causal paths and another kind of path.

There can be more than one path between a cause and its effect. Sometimes these paths are all causal processes: a gun fires a bullet which severs a rope, causing a large rock to land on a person's head just as the same bullet continues its path through that person's heart, a case of causal overdetermination. In other cases we have "mixed paths": the paths between the cause and the effect are not all causal processes as defined by the CQ theory—some paths are paths of prevention.

I have argued elsewhere that 'causation' by omission and prevention (causing not to occur) (and other kinds of causation involving negative facts or the non-occurrence of events) are to be understood not as cases of genuine causation strictly speaking, but in terms of the mere possibility of genuine causation. For example, the father's grabbing the child prevented the accident is to be understood in terms of the possibility that an accident would have been caused by certain circumstances had the father failed to act.

The chance lowering decay is an example of mixed paths. The cause, the production of Bi from Pb, caused its effect, the production of Tl, via the causal process PB-Bi-Tl; and at the same time also prevented the reliable process Pb-Hg-Tl from producing E. In general, I claim, chance lowering causation arises where an event C initiates two paths, one of which has a chance of causing E, the other a chance of preventing E, and where the actual causal path is more reliable than the prevented causal path. Causes which initiate mixed paths act at the same time to cause and to prevent the effect. Of course they cannot successfully do both, although they could fail to do both.

This formulation might seem a little awkward in the decay case since C does not strictly speaking initiate a process which might have prevented E. Rather, simply by occurring, it prevented the reliable process Pb-Hg-Tl producing E. However, it is common practice in philosophy to speak of preventing A by bringing about something incompatible with A (e.g., Gasking 1955).

Depending on the actual probabilities involved, there are two possible problems with mixed paths. First, if $P(E|C) < P(E)$ and path ρ is successful, then C causes E and we have a chance lowering cause. Second, if $P(E|C) > P(E)$ and path σ is successful, then C prevents E and we have a chance raising prevention. Chances lowering causes occur whenever the former obtains.

5. The Solution.[6] Had there been just the one path, ρ say, then it would have been the case that C caused E and raised its chance. Had there been just path σ then it would have been the case that C prevented E and lowered its chance. The problems arise, we can now see, when an event C is both potentially a cause and potentially a preventer- mixed paths.

6. In my own account of causation I do not accept this solution because, while I agree that chance-raising and causation may well be co-extentional, I think that chance needs to be explained in terms of causation and not the other way around. However, the purpose of this paper is to take for granted the tenets of the integrating approach, and to show how, granting those, a satisfactory integrating theory can work.

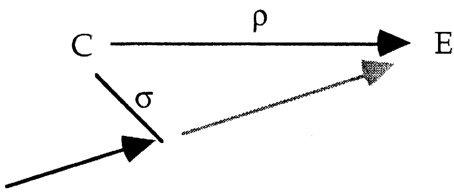

Figure 6. Decay case as involving "mixed paths".

I think there is a way to combine the process and the chance raising insights so as to account for the mixed paths. To begin, consider Mellor's concept of the chance that C gives E in the circumstances, which he writes as "$ch_C(E)$". In cases of multi paths between a cause and its effect we can (although Mellor doesn't) think of that chance as having components. Just as the gravitational force on the moon has a component due to the earth and a component due to the sun, so the chance that C gives E has a component due to the possibility of process ρ and a component due to the possibility of process σ.

In the decay case (Figure 5), C gives E a chance of 5.0×10^{-7}, which has as components the chance 5.0×10^{-7} that E will be produced via Bi decay, and the chance zero that E will be produced via Hg decay. We can write this as:

$$ch_{C\rho}(E) = 5.0 \times 10^{-7}$$
$$ch_{C\sigma}(E) = 0$$

where $ch_{C\rho}(E)$ reads "the chance that C gives E in virtue of path ρ".

My suggestion is, then, that for C to be the cause of E in virtue of process ρ, then it must be the case that

(A) C would raise the chance of E were ρ the only path between C and E.

Whether C raises the chance of E at that closest "ρ-only" world is itself a counterfactual matter, analysed as a closest world conditional (assuming here that we are following the counterfactual approach to chance raising).

(A) is not a counterfactual that can be analysed in the usual manner of Lewis (1986), because process ρ begins, temporally, with C. What we need to do is compare the ch(E) at the closest worlds to ours where ρ is the only process involved between C and E, with the ch(E) at the closest worlds to that world where C does not occur. The ch(E) at the closest worlds to ours where r is the only process involved between C and E should be the component $ch_{C\rho}(E) = 5.0 \times 10^{-7}$, whereas the ch(E) at the closest worlds to that world where C does not occur is

$ch_{\sim C\rho}(E)$, which in our decay example is zero, since C is a necessary cause of E. Thus

$$ch_{C\rho}(E) > ch_{\sim C\rho}(E),$$

so we say C is a cause of E in virtue of process ρ.

Similarly, for C to be the preventer of E in virtue of process σ, then C must lower the chance of E were σ the only process involved between C and E. In our case $ch_{C\sigma}(E)$ is zero, while $ch_{\sim C\sigma}(E)$ is one, since if C doesn't occur D occurs, which leads to E with probability 1.

This approach may seem teleological, in that it analyses chances in terms of future possibilities, but I cannot see any other way forward. In some cases of mixed paths we could conditionalize on different parts of C, if, for example, the atom's having of one quantity is responsible for one process and its having another quantity is responsible for the other (in the manner of a well-known solution to some apparently chance lowering causes; see Salmon 1984, Ch. 7). But in general it may be the same quantity responsible for and involved in both processes. In our case, this is the case. Further, there is no way to conditionalize on unknown parts of C because we already have all the information there is, if the indeterministic interpretation of quantum mechanics is correct.

Note also that in the decay case the ρ-only world is counterlegal, supposing that such decay schemes constitute laws of nature, although in other cases such as slicing a golf ball into the hole via a tree branch, the relevant ρ-only world is not counterlegal.

So the integrating account of causation that I am proposing is as follows:

C causes E iff

(1) there is a causal thread between C and E, and

(2) $ch_{C\rho}(E) > ch_{\sim C\rho}(E)$, where ρ is an actual causal process linking C with E.

Causal threads are defined as in definition 4, above.

To sum up, this account solves the problem of the sprayed plant by introducing to the conserved quantity theory a chance raising condition. But it avoids the problems with chance lowering causes by distinguishing components of objective single case chance, delineated according to relevant possible paths between the cause and the effect. These processes are themselves delineated by the original conserved quantity theory (definitions 1–3).

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