# Extraction and land in physics

by

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## Abstract

Our colonial capitalist world relies on extraction at massive scales to function—extractivism. Science is no exception. Physics researchers often justify their work through its possible technological benefits, which require ever more complex arrays of materials to function. Meanwhile, capitalist powers overdrawing resources is killing our planet. Anishnaabe and Haudenosaunee land frameworks contrast with colonial extractivism, as historied, emplaced, connected, and responsible.

I investigate ways that practices in physics are entwined with extraction. Physics writing is found to erase information about land in experimental materials, consistent with a process of extractive structures I call disoriginining. I tell a land story about indium, one of the materials used in physics labs, to connect the lab to the land. Physics phenomena are shown to also be a part of land, using the tools of Karen Barad. Finally, I suggest directions for action consistent with land ethics.

**Acknowledgements**

I wrote this thesis as a settler on the land of the Mississaugas of the Credit First Nation, previously the land of the Haudenosaunee Confederacy, governed by many laws including the Dish With One Spoon. I am between the Don and the Humber Rivers, north of the shore of Lake Ontario, north of the old shore at Davenport Road, from when the lake was bigger some 10,000 years ago. If you take Davenport down to where it changes to Church Street, go a little further south, and turn left, you can see this bit of the Don in the picture. After a dozen kilometres of flowing by the Don Valley Parkway, it runs into the lake under a couple highways.

The Dish With One Spoon is a very old law—perhaps the oldest still known on the continent. There are many parts to the law, but the main idea is to keep the land clean and to make sure there is enough for everyone to share for a long time. The Canadian state has broken this and other laws far too many times to count in the process of occupying this territory and that of many other nations, including those barring genocide. The land—which is rock, soil, water, bird, fish, coyote, human—has been stolen. And the land has been stolen from—bank from river, rock from earth, life from land. It is beyond time to return the land, and return all that we can to it.

I wrote this thesis on my laptop—a Lenovo X220. I know hardly anything about it, other than its case is made of plastic, its screen has indium in it, and its four year old fan started rattling last week. This laptop is made of someone's land, too. I don't know how to acknowledge it, yet. I think about Sumaq Urqu when I look at screens. And I wrote this thesis. It's a start.

I live by Cedarvale Ravine. I did a lot of writing in the park, there. Saw a coyote once. There's one willow tree that grows kind of sideways and is really big, so you can walk on its trunks. I am grateful to the willow and the ravine and the wetlands there for all they have done for me. I am grateful to the city, the lake, and the birds, for existing in ways that I do not understand, and I am grateful to everyone who protects this city and everyone in it. To hell with the people who fuck with them.

The infrastructure this research was done with was built and is maintained by people I have mostly never met. Thanks to the librarians, telecomm technicians, road maintainers, subway conductors, custodians, and everyone else. None of this would exist without you.

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# Chapter 1

# Introduction

I love physics. I find quantum theories fascinating to think about. I'm a particular fan of quantum thermodynamics. I love the intimacy with the universe that can be felt by learning about what its early life was like. And it just fits with my brain—I don't have a memory for anything like I do for mathematical physics. It makes me emotional to think about, actually.[1]

Because I hate it, too. Not because of how frustrating I found differential equations, or anything. I left a promising career path towards becoming an academic physicist after two degrees because I saw deeper and deeper ethical problems with the pursuit of most physics. I decided that I couldn't contribute to quantum thermodynamics if my work was going to be used, if only in a small way, towards building quantum technology, some problems with which I'll discuss below. I did this degree in science and technology studies (STS) seeking further understanding of what was wrong and seeking paths towards actively resisting what was unethical.

[1] And yes, I have cried thinking about how much I love math.

I will begin by situating the way I came to this problem through my work in physics and my experience of the militarism, colonialism, and anti-environmental techno-optimism that runs through it in section 1.1. The research questions that motivate the work are in section 1.2 and its audience and intent are in section 1.3. I summarize the arguments of the thesis in section 1.4.

## 1.1 Becoming suspicious of physics

My motivation to write this thesis is personal. I'll start with my own experience with physics to situate my research.

From a young age, I was drawn to science—a typical physicist story. I had a deep love of the world and was especially fascinated by the stuff of physics. So I decided to be a physicist. It came easily to me, I enjoyed it, and my parents and their wealth told me that I could do whatever I wanted. I ran into few difficulties before university. I was also a bit of a snooty smart kid. Being smart was what I had in this world to be good at, and I thought that made me a special person. Being a physicist was a way to be officially a special smart person, and I adopted it as an identity early.[2] I was encouraged to, too—physicists were genuinely portrayed as *special*, the stuff of their research as uniquely getting at the heart of the universe and truth, and underrepresented researchers joining the field, and thus becoming special, as a good thing.

I did an undergrad in mathematical physics at the University of Waterloo. I had no financial difficulties, few academic troubles, and experienced little queerphobia, and no racism or ableism. I experienced plenty of sexual violence at the hands of men who were

[2] Thanks to John Schanck for a particularly helpful conversation about this.

my superiors. This led to my first wave of suspicion. Clearly, people who weren't men experienced varying forms of violence in their chosen career paths as physicists. Clearly, it was causing lasting effects of trauma in many of them. And it was leading them to leave the profession. I began to create a space for feminist work and peer support in my department.

Co-founded with Jennifer Reid and Sarah Kaiser, we called that space FemPhys. It became fairly quickly a space that was epistemically different from the rest of the physics department. We platformed our own members, leading discussions about issues that we thought were relevant to physics. We started with feminism and harassment. The more work we did, the more issues seemed relevant. The group became very queer and trans. I read more STS. I wanted to know what it was about physics that made this discipline in particular so encouraging of interpersonal violence. I began to see problems in the way that physics was done. It glorified individual accomplishments, universal theories, and abstract thought. It seemed to pay, on the whole, little mind to slow collaborative work, the wildly varying particularities and contexts of the world, or projects that would help people. I became more deeply suspicious.

I moved into my master's, still at Waterloo, working on relativistic quantum information and quantum thermodynamics at the Institute for Quantum Computing (IQC). I was concerned about the way that large physics projects used resources, in a background of growing concern over the climate crisis. Various quantum projects supported military aims, including secure communications, intense computing power, and hypersensitive radar. The Canadian government *loved* the institute, and gave it lots of money to work on these and other projects, citing the importance of making Canada technologically powerful. Quantum physics was being used as a project of the nation state, to heighten its image and its power. I became angry.

For the last project of my master's in physics, I tried to situate the efforts of physicists working on quantum technology, including myself, in the context of colonialism, the military, and extraction (McKay, 2019a). I focused on a Department of Research and Defense Canada (DRDC) project which is still ongoing at the IQC to make quantum radar. This hypersensitive radar, if it works, would allow for the detection of aircraft in the Arctic, where typical radar can be unreliable due to increased background radiation from space. The Canadian state is especially interested in this because of the opportunity for "new shipping lanes and new options for resource development ... [which] requires better and more reliable surveillance" (Chagger, 2018). The Arctic, like all of Canada, is occupied territory. It does not legally belong to the Canadian state. Physics, here, was actively participating in a military project of colonialism for resource extraction.

All around me, quantum physicists were hyping up the possibility of a quantum computer. They argued it was inevitable. That it was necessary. That it would be great. I was lucky to have friends, many of them quantum physicists, engineers, and mathematicians themselves, who were also angry about these assertions. I wondered how we could act. How to connect together these scientists who wanted to resist the overall thrust of physics for war and extraction. How to avoid the grant system and the desires of the government. I wondered how to show to those who hyped up quantum computers that they were asking for the use of precious resources, acquired from the ground through inescapably violent means.

I came to York to learn about STS, education, and extraction. I have suspected for a long time that many of the problems that are perpetrated by practitioners of physics have their root in thinking of physics as something that is separate from the world. I thought that there must be a way to articulate physics as a deep part of the world—both in the sense that it is a part of world's problems, and that it is simply a part of a land, like everything on this planet. So. I am writing this thesis.

## 1.2 Research questions

My focus coming into STS was on land epistemology and understanding how extraction fits into science. I was already suspicious of the involvement of physics in extractive structures. My first goal of this project is to articulate this involvement. I will focus on how physics practices *disorigin* materials, i.e., how science work constructs ignorance of the land where stuff came from. I wondered if there was a way to fit physics into a land framework instead, to root a constructive anti-colonial direction for the discipline. My second goal is to reconceptualize physics in this frame. Finally, I came to STS from physics because I was looking for tools to change the discipline. In writing this thesis, I am exploring ways that STS can be tactically used for anti-colonial, anti-extractive work in the sciences. This last goal will be explored implicitly throughout the text.

The research questions which guide this work are:

1. How do practices of physics participate in extractivist structures, especially through disorigining?

2. How are the practices and phenomena of physics a part of land—emplaced, historied, autonomous, and relationally responsible?

3. How can STS work be usefully targeted towards science workers? How can it be purposed for anti-colonial, anti-extractive agendas?

## 1.3 Audience and intent

This is an STS thesis. I have not written it for STS academics. It is for physics and other science workers, who may find utility in a critical perspective on practices of physics.

I will be using the word ‘physics’ a lot here. I will take this word to generally mean the dominant methods and practices of the institutionally supported study of stuff like stars, particles, and fluids. These methods vary, for sure, and the institutions that support them do, too. I am focusing on the science which operates in a euro-colonial tradition. I will be taking data on the discipline from academic workers, academic ethicists, and historians of science.

I am being so broad—taking an entire discipline as a focus—because there are well-established structures and traditions which are common to many areas of research. Fluid dynamics, astronomy, particle physics, quantum physics, and more fields have all actively participated in militarism, extractivism, and colonialism. They are filled with people who did physics undergraduate degrees. Research is funded by those who have power and it benefits them in turn. The way that research projects are chosen, grants awarded, experiments designed and built, papers written—all these practices have local variations between subfield, institution, and research group. But they also have broad consistencies, especially with respect to how disconnected they are from land. It is this structural disconnection that I will address through investigating my first research question.

The intent of my investigation is to encourage a wide questioning and refiguring of practices of physics and related fields through highlighting how the science is involved in extraction. This piece of writing fits with my ongoing work in multiple arenas to agitate physicists, especially those working in Canada, into action against colonial, militaristic, and extractive violence in their work. Beyond developing a sense of how physics might fit into land epistemology, this work is about the ethics that are a part of that framework. The framework can translate into real actions.

## 1.4 Outline of the thesis

This thesis is, among other things, an ethical project. This ethical positioning is not just about what the potential impact of physics projects are—it's about how physics workers came to be in the position to do the projects at all. First, a problematization: physicists use extracted materials and are thus connected to the structures which extracted them; physics phenomena are actually created by virtue of extraction. Then, a start at responding to the problem with action.

Extractivism is an economic and epistemic framework that operates on massive removal of pieces of social and ecological systems for profit. This framework is currently dominant in our world. In order to operate, it requires hard epistemic divisions between bodies, like between worker and boss, or technology and mine. These divisions require manufactured and maintained ignorance of relationships and origins. I will call the acts of manufacturing this ignorance *disorigining*. Extractivism is extremely colonial. For centuries, groups of people have taken and wielded colonial power for the extraction of materials and value from certain people and places.

There are many epistemic and ethical frameworks which are not extractive. I focus on Haudenosaunee and Anishnaabe land as articulated in the Dish With One Spoon convenant, a law governing the area around the Great Lakes which is continually broken by colonial powers. In this framework, everything is emplaced, highly connected, historied and futured, epistemically whole, and responsible to its relations. Disorigining takes bodies from being understood in this relational context to being understood in an extractive context. There are strategies for countering disorigining. Land stories can be constructed about people and objects. These stories are geographical, historical, political, ecological, and personal. They highlight the ways that colonial and extractive structures brought the body the story is about to where it is and can motivate attendance to relations uncovered in the story. I will present this framework of extractivism, land, and disorigining in Chapter 2.

Physics is rife with extractive logics. We must understand them in order to oppose them. There is a perceived hard division between the practice of physics, the resources it uses, the resources and impacts of the technology it produces, and the decisions and structures that provide those resources. There is ample work showing that there is no such hard division between physics and society (Traweek, 1992; Harding, 1991; Prescod-Weinstein, 2020). There is also no hard division between physics and ecology, though black holes and protons are conceptually far from the complex systems of life. Physics relies on the extraction of metals from the ground and plenty more resources besides. It helped create a world where colonial power could be wileded in such a way as to use workers to tear down mountains for metals. It assumes that more technology is good, and asks not where those resources will come from. Many physicists have made weapons and other military technology to aid in war, which currently kills by a very conservative estimate some 100,000 people annually, destroys farmland, and emits a truly enormous amount of greenhouse gases (Roser, 2016; Crawford, 2019). Military power is used to enforce extraction and requires massive amounts of extracted material to function. Physics' use of ethics, where it exists, is primarily rooted in European frameworks. Typically, neither relations nor responsibility to them are prioritized in these ethical systems.

Metals are used in the lab; when they are written about in journal articles, their origin is not discussed at all. Investigating the way that indium is written about in Chapter 3, I will show that materials are typically considered in universal frameworks. Indium is nothing more than the metal which has 49 protons. Its once having been in the ground is considered irrelevant to the work. Thus the authors of these papers participate in disorigining indium, continuing the viewpoint that there are no relations to be responsible to in bringing indium to the lab or in creating new technologies with it.

One path to reconceptualizing laboratory practices is through countering disorigining with land stories. In Chapter 4, I will take a long historical look at some of the extractive and colonial structures that bring indium to laboratories. The richest deposit of indium in the world is in Potosí, Bolivia, in a mountain which has been mined for 475 years straight. It was initially opened for silver to fund the Spanish empire; it was the Spanish who forced Indigenous people to work the mine and the smelters, deforesting untold amounts of forest and killing thousands. Workers today are paid for the zinc, silver, and lead in the ore they dig up, but not the indium, which is present in trace amounts. One of the largest indium smelters in the world is in Trail, British Columbia. The settler Canadian state legitimized this land being stolen from Sinixt, Syilx, and K'tunaxa nations, in large part so that settlers could mine. Since it was established in 1896, the smelter at Trail has dumped 12 million tons of slag into the Columbia River, most of which has settled downstream in the lands of the Colville Federation of Tribes. Indium passing through the smelter is processed into high-purity bars and sold to retailers who sell it to industry and scientists. This indium is used in technology. Its single largest use is for coating LCD and touch screens. When that technology is no longer desirable, it becomes e-waste and is thrown 'away', leaching more chemicals into water, soil, and workers. This story illustrates the immense extractive structures which physics is a part of.

The very phenomena of physics depend on extracted materials. Karen Barad argues thoroughly for the inclusion of all kinds of things in the apparatus of experiments, like the cigar smoke that accidentally developed the plate Stern and Gerlach used to catch electrons. Barad relies heavily on their epistemology of quantum physics and not at all on land. In Chapter 5, I will critique their work from both of these angles, using Zoe Todd and Vanessa Watts' critiques of new materialism and my own work in philosophy of quantum theory. Prioritizing the relational framework of land requires diminishing in certain ways the epistemic authority of physics. I will then argue that the extraction of the silver on that plate and the other metals of the experiment were necessary for the phenomena of a quantized spin to *be* an observable phenomena. Without the structures that deliver extracted material to phyicists, not only would their experiments not exist, but the phenomena of a lab which are so nicely observable and quantifiable and separated from the messy stuff of the world—the objects of study of physics—would not exist.

If almost everything is entwined with extractive colonialism, what *can* we do? It is easy to feel helpless in the face of such deep and widespread bad shit. Liboiron et al. (2018a) and Shotwell (2016) speak about resisting purity at the same time as we commit to resisting violence. And physics is nowhere close to the entirety of the extractive machine, but any cog in the machine which slows or breaks can really mess the whole machine up.[3] The conceptualization of physics in a background of land rather than a background of colonial extractivism changes the responsibilities of physics workers, too. Since their work has strong connections to sites of extraction, there is some degree of responsibility to those sites. In that spirit, I offer a range of tactics for those in and near physics to resist extractivism

[3] Thanks to Ezra Teboul for this extremely hopeful remark.

and the networks of power that make it possible. Labour power and other forms of collectivism are necessary to demand change in any workplace, including physics workplaces—so, unionizing can be a good goal. Universities are interested in Indigenization—push on that to follow treaty relations. Work with Indigenous lawmakers to help physics labs follow local laws. Write land stories into journal articles. Protest with communities resisting colonialism and extractivism. Refuse work with military and for technological development; write critical perspectives on technology into journal articles. Develop protocols for doing research led by communities and their problems, and diminish the resources that physics asks of the land. More specifics and thoughts on tactics are offered in Chapter 6.

If we took land very seriously, the practice of physics would change drastically. I'm tentatively calling the changed practice 'landed physics', but really, I'm not sure it could be called 'physics' at all. We could be not just inter-disciplinary, but anti-disciplinary.[4] Loosening our grip on a need for a well-defined physics could be necessary for responsible action for a livable world.

If this work feels useful to you, find some thoughts about how we might work together in the Afterword.

[4] Thanks to John Schanck for articulating the point this way.

# Chapter 2

# Framework: extractivism, land, and disorigining

For more than 500 years, systems of intense resource extraction, labour exploitation, dispossession, and genocide have shaped the way that millions of people live their lives and relate to the earth. Physics in its modern form has been a part of many of these systems for a long time. One crucial lens on these systems focuses on extraction. Using historical, political, and ecological studies, we can see that small but powerful groups of people around the world have been at the helm of many of these violent systems for a long time. Obtaining resources has been a goal of many a violent campaign. In particular, euro-colonial efforts began a long series of campaigns which have overdrawn the earth's available resources in the interest of profit. If we are to understand the specific ways that physics is involved in these violent systems, then we must begin with understanding *extraction*. In this framework chapter, then, I'll begin in section 2.1 with an overview of extraction studies, rooting the work in an understanding of the historically deep context of widespread extractivism. We will later use tools of extraction studies to investigate relationships of mining to physics labs, in Chapters 3 and 4.

Extraction studies gives us footing to talk about some of the problems with practices of physics. *Land* will give us footing to talk about what a better conceptualization of it might be. I will introduce land from Haudenosaunee and Anishnaabe law and writings. Then, the extractivist aspects of physics will be critiqued towards the goal of being compatible with the ethical, epistemological, and legal conceptions of land. We will see that land is highly connected, specific to place, and attendant to histories and futures. It requires multiple ways of knowing, including physical, emotional, and spiritual—physics 'by itself' will not be sufficient. With all of this epistemology, the framework compels us all to act ethically and in accordance with laws like the Dish With One Spoon in the Great Lakes area. Using this framework, we will be able to ask later what physics might look like if we took relational land ethics seriously.

The colonial condition of land is one of actively maintained ignorance of a great deal of history, social relations, and ecology. This ignorance is created through many processes and structures. I will call the erasure of relations and emplacedness that a material comes from *disoriginining* and will argue that it is a core feature of extractivism. We will see in Chapter 3 that disoriginining happens in physics labs, too.

To counter extractivism, then, we can try to counter disoriginining. In the final section of the chapter, I will present land stories as a method for doing so. These are stories about where something came from, what it was doing before it was extracted, the structures that brought it out of the ground, the people who laboured and who were dispossessed, and so on. The method will be employed in Chapter 4 to connect physics labs that use indium to the sites of extraction and processing of indium.

## 2.1 Extractivism

Extraction shapes our world. It runs through almost everything we touch—the objects you own came from somewhere, after all—and through a huge amount of the work that we do. It is the process by which something in the world is removed from its context and is turned into something with value. The capitalist can then sell it and make a profit. This is rife with nonsensical moves. Here are a few examples. The worker uses their skills for forty hours a week; they make stuff or do things. Their boss takes profit from their labour—somehow, the work they did doesn't totally belong to them.[1] In a mine, rock is removed from the ground and sold. The rock is taken out of its environment and turned into something that has monetary value. The rock cannot return to the ground. In intensive agriculture, food is grown and most of the nutrients that move from the soil into the food leave the area. They might be shipped thousands of kilometres, even. Not only is the food moved and turned into something with monetary value, but the nutrient cycle is broken.

The environmental and social violence of extraction is difficult to overstate. Currently, the machinery used to mine for metals contributes 10% of annual greenhouse emissions and significant biodiversity losses Oberle et al. (2019). About 40 million people worldwide are artisanal, or small-scale, miners (Fritz et al., 2018). An enormous number of them work in toxic and dangerous situations every day, most without the support of basic PPE, supervisors, health & safety regulations, or healthcare. An even larger number of people are affected by the pollution left behind at sites where the materials are extracted and

[1] A Marxist would say that the capitalist deems some things to be 'surplus value'. Those things can be used to generate more money for the capitalist. There are many things in this thesis which can be understood in a Marxist frame, and indeed many write Marxist analyses of extraction (e.g. Arboleda, 2020; Bellamy-Foster and Clark, 2004). I won't use this language here, not because I don't find Marx useful or I wish to deny his connection to the content of the thesis. I just prefer different language. There is in particular a connection between the commodity fetish and disoriginining that is interesting but outside the scope of the thesis.

processed.

We can distinguish a bit between extractivism and extraction. Extractivism is a political and economic structure that moves enormous amounts of material out of one place to another—in essence, a political economy built on a lot of extraction (Gudynas, 2013). I will also use the word extractivism to refer to the ideology on which these structures rest. In this thesis, I am asserting both that processes of extraction are rife with violence against the structures of life and that the mindset and practice of extractivism is untenable.

Extractivism is entwined with colonialism. Arguably, violent and excessive resource extraction is a primary motivation for the colonial efforts of the last 500 years. In all that time, a metabolic rift between the capitalist and colonizing class and the worker and colonized classes has been developing (Bellamy-Foster and Clark, 2004). Labour and materials are taken from workers and (once-)colonized lands for the benefit of the powerful. Corporations and states both have built sturdy legal and labour structures to ensure the balance of power is always in favour of the extractors at the expense of the extracted-from (e.g. Girvan, 1976). The Canadian state is notable in this regard. The land now illegally occupied by this state was originally colonized by the British and French as they sought resources to support a massive empire. They have continued to exploit surviving Indigenous nations well after their efforts at genocide began (e.g. Bernauer, 2019; Cameron and Levitan, 2014; INET, 2017; Kuyek, 2019). These efforts are by no means limited to the colonial border, either. International and national law have been used to support violent efforts by corporations to operate mines in South America, often against the will of local communities (e.g. Gordon and Webber, 2018; Moore and Perez-Rocha, 2019; Cervantes and Zalik, 2018). The luxury of wealthy settler Canadians is deeply tied to these extractive practices.

The violence of extractivism is often made possible through military efforts—see, for instance, the many wars America has started for oil, or even the RCMP wielding weapons to allow a pipeline to be built on Wet'suwet'en land (Nolan, 2020; Hosgood, 2020). Extractivism in turn is used to fuel large-scale military efforts (Slowinski et al., 2013; Carpenter, 2012).

The depth of extractive logics and practice in political and corporate activities is extensive. These logics create sharp divisions. The sphere of human activity, for instance, is posited as separate, somehow, from the rest of the earth. We will see below how this separation is not present in land frameworks, and how the institution of the separation is crucial to the practice of extraction. Divisions are "powerful ways of organizing nature ... nature becomes subsumed to capital, with rivers polluted, glaciers destroyed, crops diminished, workers laid off and impoverisged, and communities in continuous anxiety and stress" (Arboleda, 2020, p. 194). A similar division is made between the activities of physics and the exploitation of people and land for profit. I will show throughout the thesis that this division is in the interest of extractivism and that we need to reframe physics as a part of land.

In this thesis, I make use of a mindset prevalent in extraction studies: that extraction is in many ways at the core of capitalist colonialism and that it is a practice aimed at humans, their labour, and their ecosystems. I will talk in Chapter 3 about how scientific writing, laboratory practices, and the trajectory of western physics participate in extractivism. I rely on work that uses methods of environmental world systems (Moore, 2003), economic anthropology (Francescone, 2018), and colonial history (Pryce, 1999) in Chapter 4.

## 2.2 Land

There are many non-colonial, non-extractive ways to understand the world. In this thesis, I use an understanding of land informed by Haudenosaunee and Anishnaabe law and writing. I will contrast some practices of physics with this framing of the world, and then situate those practices constructively in this framework. I will also critique Barad partially from this framework. To do this, I will define what I mean by the word land: an epistemic & ethical framework that is relational, emplaced, autonomous, historied & futured, responsible, and epistemically whole. Before I outline the framework, I will situate myself.

I am not Haudenosaunee or Anishnaabe. I am a white settler with family mostly from England a generation or several back. My understanding of land should be taken in this context. I am not an expert. I did not initially seek knowledge about land for this thesis or for purposes of scholarship. I started to learn about land becuase Indigenous people in media and around me pointed out that I was participating in colonialism and spoke about the importance of their laws and worldview. If I wanted to help oppose colonial rules, I needed to reckon with who I was as a settler and how I could help move settler society towards following laws like the Dish With One Spoon. Since I had to reckon with who I am, learning about these things changed me. And they should change settlers—we can't work within harmful settler epistemology and successfully oppose colonialism. Rene Meshake (2016) taught me about agency, intention, and relation when he told a group of students that that you should "let the story change you". The way I have experienced land for most of my life is the way that many settlers experience it: as substrate, surface, inert, as something without history. I was raised in a disorigined world, and I looked to land to help me understand history and connection. This shapes my engagement with work about land.

Land is an epistemic & ethical framework for the material ecological world—Vanessa Watts (2013) calls it Place-Thought. It is law. Watts tells of the Sky Woman and the First Woman, historical accounts which hold important elements of worldview which are a part of Anishnaabe laws. Understanding that humans are "made from the land," Anishnaabe understand that "the female earth... is intrinsically tied to the notion of sovereignty and how humans interact with non-human creatures in the form of governance" (Watts, 2013, p. 27). Colonial frameworks rupture this connection, "disabling communication with Place-Thought" through genocidal actions like putting Indigenous women in prison in order to be able to extract from the land (Watts, 2013, p. 31).

This framework relies heavily on connectedness, or relations. Kimmerer (2013) and Hill (2017) talk about the specificity of connection between each being involved in the entire system of life. Prioritizing these relations means that the interdependency we all participate in is acknowledged up front and is celebrated.

Land is very specific to place (Watts, 2013). The relations that one can depend heavily on the place, especially if one is genuinely connected to the other living beings there. For instance, the food one eats depends on the rock and soil, the seasons, the water. One cannot, therefore, come to know all land. Each land is specific, with its particular contingent possibilities.

Everyone and everything is a part of land, and they all have autonomy . Since each nation of people, animal, plant, water, and rock have their autonomy, the land belongs to itself (Watts, 2013; Simpson, 2008).

Places often exist for long periods of time, and it takes a long time to get to know them well. In the framework of land, time is thus very long (Sheridan and Longboat, 2006). Both the future and the past figure strongly into considerations about the present.

Maintaining the relations one has means being responsible to the other beings involved in the relationship. The responsibility will be particular to each relation, and they won't always be relations of equals. Time being long means being conscious of how one's actions will ripple out long into the future. Specificity of place means being very attentive to each location, and not attempting to transport knowledge or practices between locations willy-nilly. Kanonhsyonne Janice C. Hill (Mohawk) writes that she operates under the "original instructions as given to us by the Creator include our relationship and our responsibility to the land, the cosmos, and everything in between" (Robinson et al., 2019, p. 23). Many laws exist to shape responsibility and ethics. Without needing to adopt Haudenosaunee original instructions or a Haudenosaunee identity, working with land can call all of us to attend to responsibility in our relationships.

Land is not made of words; nor is it made only of animals, or feelings. An epistemic wholeness is required to participate fully in land. Knowing in more than just an intellectual way is necessary—spirit, emotion, and process are also important (Kimmerer, 2013; Porter, 2012; Absolon, 2012). To isolate any of these ways of knowing from the others is to seek a picture that is less whole than it could be. This also means that, in addition to the limitations on my explanation from my settler perspective, there is much that cannot be communicated about land in a text. Each bit of land has information and experiences that can only be learned in physical and spiritual ways.

Land is wealth. To have clean water, good food, and a strong more-than-human community that you trust to last well into the future is surely the wealthiest one can be. More than that, everything that we currently measure as wealth comes from land. Metals, of course, and also food, and the money that is made off of other people's labour (because people are a part of land). The practice of extraction is one of stealing this wealth, in two ways. Immediately, it takes gold from ore, time from people. Then it steals the future, leaving tailings ponds filled with mercury for generations.

### 2.2.1 The Dish With One Spoon

To be more specific about land, let's dig in to the Dish With One Spoon, called Gdoo-naaganinaa in Anishnaabemowin and Sewatokwa'tshera't in Mohawk (Marin-Hill et al., 2008; Simpson, 2008). This agreement is one of the oldest laws on the continent (Nah-wegahbow, 2014). A wampum belt was tied to represent the making of this agreement between the Haudenosaunee and Anishnaabe confederacies in 1701 (Williams, 2018). On the belt there is a dish containing a nutritious meal (often told to be beaver tail) (Camastro, 2019). Eating a good meal together means we will come together to talk and work together in a good mind. There is a longer side of the dish; that is where the spoon rests. The dish is the land: there is only one. We must keep it clean. There is only one spoon—we need to share. The belt is long, like time. The land has existed for a very long time and will continue to be here. We must ensure there is enough for everyone well into the future. There is no knife; we must not use violence when we work together.

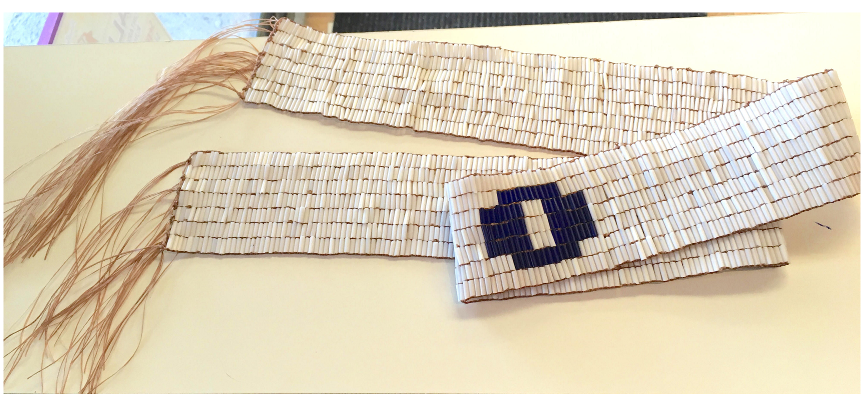

Figure 2.1: A reproduction of the Haudenosaunee Dish With One Spoon wampum (Brant, 2017).

The dish is land, and we can contrast the legal context of the dish to the colonial legal perspective on land. For the Canadian state, land is something which can be owned by a person or the Crown (Seawright, 2014). The dish is different. It is eaten from—it provides food and fuel. It is shared. It can be kept clean. There is no option to do whatever you please with the land, which is what it means to own something. The actions one takes with relation to the land always affect the people who are also living with it, who are also eating from the dish. The land does not belong to people. People are a part of it. The land is made up of all these nations—people, animal, plant, water, and rock (Watts, 2013; Simpson, 2008). The land belongs to itself.

The jurisdiction of the Dish With One Spoon is different than colonial laws. It applies to the land, which includes the people. All nations that inhabit this territory around the Great Lakes are welcomed into the agreement. It is unfortunate and shameful that the Canadian state has broken the agreement over and over again in despicable ways, including by becoming a state governed by violent laws on stolen land.

This is a law governing the behaviours of individuals and nations. Each nation involved has "particular responsibilities to live up to in order to enjoy the rights of the agreement" (Simpson, 2008, p. 37), meaning that sovereignty of nations can be maintained through the agreement. Particularities are important, here: the wampum was made by the Haudenosaunee, not the Anishnaabe, and elements of peace are more important in the Haudenosaunee relationship to the law than the Anishnaabe (Simpson, 2008).

The Dish with One Spoon, being bound to the lands that I have grown up with and still work on, is not tied to lands everywhere. It was made by specific peoples. There are many more specifics of *how* to care for land and each other that are specific to this wampum and to many more of the laws of each of the Haudenosaunee and the Anishnaabe nations.

As a settler on land that this applies to, it is my responsibility to come to know how I can participate in upholding this law. It is also useful in that it provides a good sense of some overarching themes of land: land as something with a long history and future, land as relations between nations which belong to themselves, land as that which bounty comes from and that must be shared and cared for peaceably.

This epistemology and ethic can be used for physics and to respond to extraction—especially on the colonized lands of Turtle Island, where the land-based law of the Dish with One Spoon and the other laws and practices of the Haudenosaunee and Anishnaabe nations have been violently overturned by colonialism. To live on this land is to have a relationship with it; to be responsible to it is to oppose colonialism, even in physics.

## 2.3 Disorigining

Dense networks of relations between biotic and abiotic elements have long histories, and this constitutes the world. Yet extraction operates in this world. In order for extraction to happen, relations must somehow be broken. Let's investigate how this happens.

How is it that rock can go from being a part of a mountain with an ecosystem atop of it to slurry in a smelter to a commodity to sell? First, a social effort must be established in order to collect the tools and people and finances that make up a mine, whether it be an individual artisanal effort or a mega-mine. Often, there is coercion of some kind involved in some of the labour, including a need for people to perform waged labour because they no longer have access to land which provides food and resources directly. The rock is physically extracted. It undergoes a variety of chemical and geographical changes. Different elements are separated out using heat and acids and amalagams. The rock is moved to a local mill, where it changes into a concentrate, and then is shipped to a smelter probably quite far away, which turns it into a fairly elementally pure object. There are many connecting processes here which physically remove the rock from its relations in the land, beginning with its being cut out of the earth. That is when it can no longer provide its presence to its relationships in the ecosystem. But its original context lives on in some way through the rock in its geological makeup. The process of smelting slowly strips that away, too, and metal from different places on the planet may be mixed together during smelting, until there is no physical way to tell from looking or testing where the atoms of a metal came from.

At every stage of this journey, the metal (or what will be or what once was the metal) is where it is because of a long history of relations, some local, some global, some human, some not. And it shapes them back. In some way, the metal may become a part of the land in every place it moves through.

Along the way, various structures remove information about relations and history. Some of these are physical: smelt a rock into a metal, and lots of geological information is lost. Some are economic: the supplier of an ore, a slurry, or a metal are rarely shared with the purchaser, since that's valuable market information. Likely, many of the sources are purposefully obscured in order to be able to perpetuate exploitative labour practices and other violences .

I will use the word *disorigining* to refer to the complex process of removing information about the relations that an object has been a part of. Disorigining is a central tool of extraction. It removes a sense of history of the material, preventing a sense of future about it. It removes a sense that the material has or has had relations. It allows the material to be viewed exclusively as a commodity or a tool.[2] In being removed from land *and* in being removed from being perceived as land, the material is now able to be considered in an extractivist colonial ethical framework. It is no longer able to be considered in the framework of the Dish With One Spoon, since we do not even know what relations it could have.

## 2.4 Countering disorigining with land stories

Even when the majority of physical characteristics which might link something back to its place of origin are lost, the object still has a history. Even if no oral or written stories accompany it, the history still happened. We can counter disorigining through various methods of noticing, researching, listening, and storytelling. I will here discuss object-and-land-centred storytelling that I'll call a land story.[3]

There are long traditions of maintaining history in very active ways across Turtle Island Indigenous nations—ceremonies that recite stories which are both history and law, detailed expressions of gratitude, and invocations of the land. Susan Hill writes that for Haudenosaunee, "the very core of our existence is formed around the historic inheritance passed down through the generations" (Hill, 2017, p. 1). There is a long-standing practice of transferring valuable local knowledge from one generation to the next. This history also relies heavily on the land, as it is full of constants, in comparison to brief human lives.

[2] Here, we see a connection to Marxist fetishism. The connection is slightly out of the scope of this text.

[3] Two other methods that have been influential here are media archaeology and implosions. They both have significant overlap with land stories and are not engaged with in detail here in the interest of brevity. Media archaeology attends to the histories and futures of technological objects. Excellent pieces include Gabrys (2011); Bronfman (2020), and Parikka (2015). Implosions are a method that seeks to ask as many questions as possible about the histories and circumstances that produced or are embedded within a particular object. See Dumit (2014).

"[L]and and territory are the prime determinants of Haudenosaunee identity" (Hill, 2017, p. 3), so knowing the land is of utmost importance.

It is partially this fact of culture that has led settlers to adopt the practice of land acknowledgements at the beginning of their meetings and events. The current popular forms of land acknowledgements run from being distinctly colonial to a mix of settlers coming to know land. Certainly the most popular practices currently used in Canada are little more than a list of the human nations in the vicinity and some expression of gratitude for the land. The amount of information they carry is slim. They do little to challenge colonial understanding of land or to explain the history and thus the responsibility for the forces which stole it. These kinds of land acknowledgements perversely reinscribe settler colonial structures by simply stating their existence. More informative and challenging acknoledgements describe some history of the land and critique the colonial forces which brought the institution or event into being.

Dylan Robinson offers the poem *Structure for acknowledgement* (2019) on the embodied practice of acknowledging land in a way which engages the physical land and the structures that brought it to where it is. It is worthwhile to reproduce the poem in full here.

> *I am sitting in a room. Limestone walls surround.*
> *Limestone lines*
> *inside and outside of the structure I sit within*
> *This building, this house, this room,*
> *is one of many*
> *I am living in a city—"often called the Limestone City"—says the City of Kingston*
> *I am spending my days in limestone buildings*

*I sit inside many "of the many charming limestone buildings," says the city,*
*"many of which help tell the story of Canada"*
*These charming limestone walls—this charming city—built from quarries*
*Quarried from the lands of Haudenosaunee and Anishnaabe people*
*Built from the lands of the Haudenosaunee, the Anishnaabe*
*Structured by colonial design*
*to allay anxieties of impermanence*
*I am sitting in a limestone room that hums*
*with the subfrequency of colonial quarry and cut—*
*this audible-inaudible sound—resonates my body*
*My body—xwelmexw body, swiyeqe & yes xwelitem starving person's body—*
*in this room, these buildings, that resonate the story of Canada*
*I am listening in a limestone building, trying not to feel the story of Canada*
*resonate through my body*
*shiver through*
*I am trying instead to hear the seepage of water through stone*
*I am trying to hear the labour of quarry, cut and chisel*
*I am trying to hear if these walls are also still the land*
*I am trying not to hear these walls declare their immovability, declare their charming structure, their necessary structure,*
*I am trying to hear their structure burn down*
*while the shelter for our work remains* — (Robinson et al., 2019, p. 22).

Robinson connects with a physical, geographical history that is erased by the words of the City of Kingston, which seek only to put architecture in service of a "charming" history of Canada. He hears the way the limestone was removed from stolen ground. And this is motivating to undo the colonial structures which allowed that to happen—and perhaps the limestone structure itself, while retaining some kind of structure for shelter.

We can work from this poem in combination with another form of land acknowledgement practiced by settlers: the land story. These stories come in many forms. Often, they are geographically rooted histories of where the speaker and their family come from, in order to situate themselves. Other times, they are an experience of being in or a part of land. Always, they relate the history and experiences of the speaker to the structures of settler colonialism and attempt to subvert them by making relations known. They are recited or performed out loud at the beginning of a meeting or event in order to root people to land, dispossessed nations, and anti-colonial struggle.

Researching and telling land stories are methods for identifying relations and responsibility and centring those responsibilities in the work which follows them. The research uses tools, however informal, from history, ecology, political economy, feminist & postcolonial STS, and more disciplines. It often involves a great deal of personal reflection: in light of this information, what can the person telling the story say about their own life? The way they have been taught or expected to live it? What ways could they behave differently? It can also be rooted simply in noticing, especially in the way that stopping to stare at a bush filled with flowers will reveal, after a second or two, hundreds of buzzing insects that you couldn't see while walking. Noticing is a powerful way to build relations and respect.

Telling a land story is an act which emphasizes to the speaker and listeners the contents of the story and their importance. The experience of speaking the story out loud and of hearing it can generate a sense of shared responsibility for harms and the motivation needed to address them. Like other kinds of discussions, it has the potential to act as a consensusbuilding tool in bringing epistemic cohesiveness to a group or acting to highlight epistemic conflict.

Land stories tend to centre on humans: what relations, small and large, brought someone to where they are? How does the human telling the story experience the plant nations in the city, or the seasons, or food? They also involve the immediate surroundings of the human, and how that human can be more responsible to them. Bodies that we typically think of as objects have land stories too, as Robinson so deftly demonstrates. Everything comes from somewhere. Everything has relations. All matter on this earth is part of a network of biotic and abiotic, human and more-than-human elements in some way.

We could start with where a material originated. For metals, this would be where in the earth's crust it had resided for millions or billions of years before being disturbed by humans. There were relations there: the ground is part of an ecosystem. It provides the right nutrients and pH and other factors for certain kinds of plants to grow; creates geological features like ravines or mountains amenable to some life more than others; slowly dissolves into water and soil to distribute minerals to life beyond the bounds of its rocky existence.

The forces that extracted the metal from the ground are part of the story. Who was it? For what intention? Who benefitted? Who laboured, and how dangerously? How did the extraction change those relations, and for whom?

Then, like the people who tell histories about how their families of British origin ended up in Southern Ontario, the metal moved, from ground to smelter to distributor to lab, and beyond, to tech and to e-waste site. As noted above, as it is moved, the chemical composition of the metal changes drastically. It begins as a part of ore, as rock, and is doused with mercury or solvents and subjected to a lot of heat to turn it into something chemically pure. And then it is combined with chemically pure atoms from other places, transformed into all kinds of materials, which are constructed together into material technologies. The technologies are distributed and used—mediators for more relations. Some day they cease to be useful and are relegated to a drawer or an e-waste bin. Maybe they end up in the hands of a worker who uses more solvent to try to turn the technology back into a collection of chemically pure atoms.

There are limitations to this method, as will be discussed further in Chapter 4. Mostly, the limitations come from the enormous amount of history and relations any one object has, and the usual difficulties in collecting and presenting them.

In the next chapter, we will see a set of physics work that helps to disorigin the metal indium. In Chapter 4, I will use a land story to counter this disorigining, on the way to constructing a physics that is more rooted in land in Chapter 5.

# Chapter 3

# Extractivist logic in the practice of physics

How do current physics practices fit into extractivism and land? This is a bit of a big question. My main goal in this chapter is to show that there is a lot of extractivist logic in physics and not much land. If we can understand how this logic is active in the discipline, we'll be much better situated to confront it.

I'll start with some background on the field's relationship with war and extraction in section 3.1. Many physics workers have developed weapons and been funded by war agencies—war is a tool used for and made possible by extraction, so there's a major connection there. Many projects in the field have produced new technologies which have provided motivation for mining and refining industries to expand. What about ethical frameworks? Much of how ethics is discussed in scientific frames is eurocolonial, not relational.

This is the context in which I will investigate more specific practices of physics in section 3.2: professional writing about experiments which use a metal. I look at peer-reviewed papers discussing research that uses indium, a low-abundance metal considered crucial to modern technology-heavy society. In these papers, we will see very little reference to any of the elements of land, and instead an implied responsibility to develop new electronics. All this absence of knowledge will beg a new question, addressed in the next chapter: how is indium a part of land?

## 3.1 Background

Let's begin with some background on the discipline of physics, to further motivate the project of the thesis and the specific investigation later in the chapter. This is not background in the sense that physics has been done while in a background of colonialism, extraction, and war. Physics has been integrated in those things, and specific workers and projects have been responsible in them. All of these connections are massive—this section is, again, just an overview.

### 3.1.1 Physics and war

Physics has a reputation as a discipline for weapons manufacture, and it's not without reason. Not only have massive weapons projects been a core part of the practice for well over a century, but this military involvement, sometimes referred to as the military-industrial-academic complex, significantly shaped the entire discipline.

Let us first take a brief look at weapons development. Of course, the major examples are atomic and hydrogen bombs. Physicists worked on the underlying theory, proposed the atom bomb project to the Eisenhower administration, and worked it to completion (Hughes, 2003; Szilard and Einstein, 1939). During WWII, physicists also developed several kinds of radar—a project with a similar expense and possibly more effect on the war effort than the bomb (van Keuren, 1997; Sarkar et al., 2016). Physicists were employed in the Strategic Defense Initiative, also known as Star Wars, in 1980s America (Reiss, 1991; Mosco, 1987). The plan was to build a space-based laser anti-missile defence system; it never got off the ground. Fluid dynamics and aerospace research has been immensely useful for ballistics, planes, and ships (e.g. Bengtsson et al., 2019; Eckert, 2007). GPS and associated gravity-mapping technology was crucial to be able to aim inter-continental ballistic missiles. Quantum information research is wielded for intelligence services (i.e., the computer-based war organizations) (Raymer and Monroe, 2019). There are even projects like quantum radar, continuing the WWII tradition of improving sensing for war (McKay, 2019a).

Individual physicists have of course resisted the overall trend of militarization. Joseph Rotblat refused work at Los Alamos during WWII, eventually writing a Hippocratic Oath for scientists (Rotblat, 1999). Charles Schwartz asked the American Physical Society (APS) to take a vocal stand against the Vietnam War and was reprimanded by UC Berkeley for requiring his students to take a Hippocratic Oath much like the one Rotblat wrote (Schwartz, nd). Schwartz and others founded Science for the People in the post-war era, an organization that protested and wrote against imperialism in science (Moore, 2008). Organized resistance from physicists appears to not have made it into the fabric of any major physics institution.

Thought there was resistance, the way the military shaped physics ended up being enormous. Prior to WWII, there were zero federal dollars allocated for physics research in America; the non-federal funding was about 1 million 1938 dollars. Post-WWII, the federal funding skyrocketed to $40 million—about 20 million 1938 dollars (Forman, 1987, pp.

188-189). This money was awarded by the Department of Defense and the Atomic Energy Commission, which was the organization created from the Manhattan Project. Given the success of solid state physics in radar and nuclear physics in the bomb, these fields received an enormous amount of this funding. The number of solid state PhDs increased five-fold during the 50s, compared with a two-fold increase in all physics PhDs (Forman, 1987, p. 204). In the 60s, solid state became the largest subfield recognized by the APS and has held that title ever since (Martin, 2019). The size, funding, and power of physics (and some fields of physics more than others) is primarily due to its utility in war.

This is part of the background in which physics is conducted today: lots of military funding and little resistance. This background helps in seeing extractive colonial logics at work in physics. Colonialism is carried out through violence, including state-supported military violence. On a structural level, physics workers have participated in significant ways especially in the expansion of eurocolonial military might in the 20th and 21st century. Thus, we can expect that there are logics present that justify these actions, rather than logics that would have physicists first attend to responsibility in relations.

### 3.1.2 Physics and extraction

Though not quite as illustrious and direct as its relationship with war, institutional physics has also had a long history with extraction. War is a tool wielded for extraction, and extraction is performed to support war. Every time physics has supported war (which is, as just noted, many times), it has also supported large scale extraction. Physics workers have created many new technologies, sometimes depending on new extractive projects. Plenty of direct, field-specific examples exist, as well, including the use of astronomy for the slave trade.

Some physics work is done directly in support of extraction, like much work in geophysics (Parasnis, 1973). Astronomy has been employed in the violent extraction of human lives, for navigation in the transatlantic slave trade (McClellan, 2010).

I said in section 2.1 that the wealth of settler Canada comes from colonial extraction. This is true, also, for the wealth that is the ability and societal intent to practice physics on a large scale. It takes substantial resources to launch a spacecraft or accelerate protons to 99.9999% the speed of light. It takes land to build a permanent observatory, stolen in California or Hawai'i (Minsky, 2020; Maile, 2015).

The work of physicists has often been directly involved in the creation of new material technologies, like the just-mentioned atom bomb, or GPS, or integrated circuits. These technologies require extracted materials. Nuclear weapons and energy increased demand for uranium dramatically, with previous mining efforts for vanadium in the midwest often discarding uranium as waste (Voyles, 2015, p. 2). Mining, processing, and discarding radioactive materials is replete with environmental and social harm. Every other technology physicists have had a hand in has a similar story. I will continue to pick up on this thread throughout the thesis—technology development links physics work to extraction in a major way.

### 3.1.3 Physics and ethics

This thesis is, in part, an ethical problematization of the practice of physics. So, we should probably have a little background on what ethics have already been done in the field. There is a wide range of approaches, and my review here is not comprehensive. Overall, little attention is paid to ethical questions in physics. When it is, the questions are usually about weapons development and they are usually asked using eurocolonial ethical frameworks.

Here is an overview of those systems with arguments as to why they are insufficient.

Often, the approach is highly individualistic. Greer (2017), for instance, suggests that scientists develop their own value system in which to practice science and stick to that. She suggests that each scientist begin with valuing human life and scientific truth, and add or modify values according to what they are comfortable with as an individual (p. 4). This approach is rooted in the deontological framework, where each individual does their best to follow a set of rules. What this framing misses is a foregrounding of responsibility to the relationships that people have as scientists and parts of land.

Many of the texts focus disproportionately on research misconduct, spending a small fraction of pages late in the book attending to "science and society". D'Angelo (2019) spends a majority of his book discussing fabrication of data, issues with citation, and misconduct in peer review, opening with a section titled "Crimes against Science" about misrepresenting data (p. 4). The assumption in this presentation is that the pursuit of science as it currently exists is overall good and justified, that its relationship with society does not need to be deeply investigated and queried. Greer (2017) proposes justice as a primary value of scientific ethics, and defines it as "respect for the lives of other people in science, and respect for the truth about their contributions" (p. 5). Even justice, for the scientist, is limited to those people who are somehow directly involved with the process of science, rather than justice for scientists as a corollary of valuing justice for all.

Though valuing human life is a primary concern in the dominant narrative of scientific ethics, human life and society tends to not be conceptualized as part of an ecosystem. Scientists are implored to be responsible to the people who are their research subjects but not to consider that perhaps their duty to the health of land is their first duty. D'Angelo spends one page discussing issues of "science and the environment" and focuses primarily on the necessity of being honest in that research. With respect to the limited resources of the planet, he offer that scientists must consume resources "responsibly but not in a way that takes the resources away from others. We should (and) do our part to find alternative sources of raw materials and energy" (D'Angelo, 2019, p. 86). It is not clear what "alternative sources" exist that don't take resources away from anyone else.

Whitbeck (2011), writing a text about engineering ethics, approaches the environment in a more fulsome way. She explicitly says that the environment is not merely a background, but is an "integrated system" (p. 352). This view is attributed primarly to Rachel Carson's influential book *Silent Spring* (1962), with a vague mention that it may overlap with non-Western perspectives that existed well before the 1960s. The problems she presents are those which canonically fall into environmental engineering problems, like oil spills and chemical dumping. The ethical framework presented is rich and useful, yet still misses the dependence of engineering on systems external to it—the extraction which underlies science and engineering.

Though it has been meagerly taken up in physics, much work has been done on Indigenous and decolonial approaches to ethics in science. As discussed in Chapter 2, these ethical systems generally take relationships to be fundamental, rather than individually-decided sets of values. They also incorporate existing systems of power and the need to respond to them. Tuhiwai Smith (1999), for instance, presents an "Indigenous research agenda" that would seek to orient science as one of many tools that can be used for Indigenous peoples' survival, recovery, development, and self-determination. In order to do science in this context, a strong ethical framework must be used that is based in respect of people and planet.

Many scientists themselves have worked to resist colonialism by ethically reframing their work. On the biologist-hosted blog *Decolonize All The Science*, McLean et al. (2017)

explicitly recognize the colonial history of science and the need to shift research agendas "to meeting the needs of colonized people and their larger struggles for self-determination." Not only this, but they position ethics as fundamentally about care through meeting others' and our own "basic needs and legitimate expectations", aligning with a broader trend in STS and decolonial thought.

The vast majority of these works apply to the social and biological sciences. Very valuable work has been done in astronomy by many resisting the Thirty Metre Telescope (TMT), which many Indigenous Hawai'ians did not want installed on the sacred mountain Mauna Kea.[1] That years-long fight seeks to instill Indigenous self-determination and respect of the sacred as a central necessity in astronomy, and in all science (Maile, 2015). Interestingly, the stance of anti-TMT organizers was very explicitly pro-telescope. The place and its blatant colonialism was the only thing at issue. Yet the telescope is planned to be built with a thirty-metre wide mirror, in an eighteen-storey dome. As Haraway asks, "with whose blood were my eyes crafted?" (Haraway (1988), quoted in Dumit (2014)). Where does the glass for the mirror come from? Whose land does that dome come from? When do they get a say?

I am writing an ethical problematization of the practice of physics at its root by contemplating science's dependency on extraction, which further depends on capitalism and colonialism. Science in society is not but one consideration to make in ethics; science on and from land is the root from which to consider ethics. Neither can only the effects of a scientific project be taken into account; we must consider where its resources come from.

From this background of physics integrated in a context of war, extraction, and ethics compatible with extraction, we can now investigate some specifics of how lab work can

[1] I am grateful to Chanda Prescod-Weinstein for her Decolonizing Science Reading List, which includes a collection of writings about this resistance (Prescod-Weinstein, 2015).

participate in the extractivist function of disorigining.

## 3.2 Is land acknowledged in the lab?

I have just given an overview of extractivist logics in the field of physics at a macro scale. Now, I turn to the scale of labs. How do physicists see materials they use in the lab? What relations with those materials and the structures that produced them are acknowledged? How, then, is responsibility constructed or ignored? Understanding some of the specific ways that practices in physics uphold or further extractivist practices will be useful for the goal of changing the way the field participates in extraction overall—local, small-scale practices are an entry point for action.

When I began this study, I had some indications about answers to these questions. In my experience, lab workers are unaware of the ultimate source of their materials—as can only be expected from the extent of disorigining in the world. Further, I was not familiar with labs who were interested in this question. I had never read a paper or listened to a presentation where materials sourcing was included. Based on these limited experiences, I anticipated that I would find little evidence of place, history, future, relation, autonomy, or responsibility in records of labwork.

To concretely capture indications of the ways that physicists think about and interact with indium in a professional context, I perform a content analysis of nine recently published studies which make use of indium (Hsieh and Shannon, 2005). I looked for themes in how indium is represented and used and its presence is justified. On the whole, the writing indicated that indium was primarily associated with its universal properties, with no mention of its earthly origins. Indium is presented as if it is not emplaced or historied and like the scientists have no responsibility to the relations that produced it. Land is not considered in these papers. I will argue that the production of writing where land is not considered actively participates in disoriginining—constructing an image of indium with is consistent with extractive rather than land logics.

### 3.2.1 Method

To collect the texts, I searched on the arXiv (an open-access repository for papers in physics, astronomy, and math) for papers that included the word 'indium' in their abstract submitted to the site in the last year. 98 papers fit that criteria. For workability of sample size, I picked nine papers that were also published in peer-reviewed journals and made use of indium in an experiment. The nine papers were mostly in the fields of materials and nanoscience; one dealt with "fundamental" research into nuclear structure.

In the texts, I looked for references to indium, explanation of the experimental process and results, justification for the project, mention of waste, and mention of sources of materials. There is strong similarity in the way these things are discussed across the papers.

### 3.2.2 Data

#### Content of papers

All papers describe experiments using indium. Ovadyahu (2019) evaluates the effects of thermal treatments on thin indium-oxide films by measuring their resistance. Kulesh et al. (2020) create and study indium antimonide quantum dots, a technology intended to be used in a variety of quantum communication and computing. Lei et al. (2020) improve a bit of superconducting circuit architecture, intended for quantum computing, with a technique called indium bump bonding. Sahoo et al. (2020) don't actually import indium into the lab; they create indium isotopes from uranium carbide and lanthanum carbide in a particle accelerator. The paper compares the measured radii of these isotopes with values calculated from a new method. Yuan et al. (2020) do another superconducting study on two-dimensional electron gases in indium arsenide wells. Mazzolini and Bierwagen (2020) use indium as a catalyst for molecular beam epitaxy to grow gallium oxide thin films for two-dimensional electron gases. Zhao et al. (2019) build thin films of indium selenide for use in flexible electornics. Carrad et al. (2020) present a new fabrication tool that "eliminates the need for etching" when creating superconducting circuits on a base of indium arsenide.

### Sourcing and waste

Of nine papers, only one (Lin et al., 2019) notes the company that the indium was purchased from (in this case, from Indium Corporation of America) (Lin et al., 2019, p. 17). Two more papers make one mention of the purity of the indium used (Ovadyahu, 2019; Zhao et al., 2019).[2] This is one of the only recognized features of lab-grade indium which distinguishes different samples from each other. In the idealized style of scientific writing, only those details which are deemed relevant for sufficiently justifiying results are necessary to include. The process of acquiring indium or whose hands it passed through to get to the lab is not important enough to the results of the experiment. Meanwhile, the brand names of equipment like lasers, tape, oscilloscopes, and magnetic shielding were mentioned in seven papers (Carrad et al., 2020; Lin et al., 2019; Ovadyahu, 2019; Mazzolini and Bierwagen, 2020; Zhao et al., 2019; Lei et al., 2020; Sahoo et al., 2020). None of the papers discuss the amount of indium or any other material used.

[2] High-purity metals are sold at different grades—99.99% indium atoms, or 99.999%, or higher.

In experimental processes, there are wastes generated. In nanofabrication facilities, for example, many steps of fabrication involve large quantities of solvents that devices on chips must be dunked into, and the solvents then disposed of. In Carrad et al. (2020), this process is described simply as "[t]he resist was removed and the InAs was subsequently..." (p. 8). There is no mention of what solvent was used or where the solvent and resist were disposed of. One of the measurement processes in Yuan et al. (2020) destroys a piece of their sample device: "We note that although the single-turn coil is destroyed in each shot, the sample and pick-up coil remain intact..." (p. 5). Again, there is no discussion of where the destroyed coils end up.

### Elemental indium

Every paper reviewed referred to indium or an indium compound through universal properties, a mode of viewing materials identified by Oakley (2015) as the 'elemental' conception of a substance. Indium is referred to by properties that are taken to be observer-independent in simple statements like, "indium superconducts at 3.4 K" (Lei et al., 2020, p. 2), "InSb is a promising material ... with a high carrier mobility, large g-factor and strong spin-orbit interaction" (Kulesh et al., 2020, p. 1), and even just by referring to "the indium (In) atom (Z=49)" (Sahoo et al., 2020, p. 4)—Z is the number of protons in an atom.

Though the number of protons in an indium atom is truly universal (it is the defining feature of an indium atom), these other properties are only *almost* universal. No block of indium is made entirely of indium atoms. This doesn't make significant effects on the properties that materials scientists refer to as universal—just tiny ones. It just means that all blocks of reasonably high-purity indium are very similar, rather than identical, as the language used in these papers superficially suggests.

Oakley (2015) emphasizes that distilling a substance to its comparative properties (e.g. "high carrier mobility" (Kulesh et al., 2020, p. 1)—high in comparison to other materials) is widespread: "this perspective is underpinned by the cultural dominance of the scientific definition of reality, in particular the discipline of chemistry as a way of 'knowing' matter (Schummer 2008)" (Oakley, 2015, p. 159).

### Technical goodness

Every experiment is presented with some kind of justification. Eight of nine papers justify their experimental work through by its potential utility for technological applications; six are specific in which technologies they are doing research for. In one case, the technology is introduced without an explicit value judgement, like in this introduction of the application of an indium compound: "Josephson junctions made out of AlInAs have been used for tunable superconducting qubits..." (Yuan et al., 2020, p.1). The other mentions of technology, however, included descriptor words like 'important', 'promising', and 'crucial'. Carrad et al. (2020), for instance, describes their desired material property of "[u]niform, defect-free crystal interfaces" as "crucial ingredients for realizing high-performance nanoscale devices" (p. 1). Lei et al. (2020) begin their paper by saying that the circuit element they are trying to develop is "important in building... quantum computers" (p. 1).

Implicit in all of these justifications is the judgement of the particular technology as a good and worthwhile use of material, economic, and human resources. Who would care about "crucial ingredients ... for nanoscale devices" (Carrad et al., 2020, p.1) unless the nanoscale devices were also crucial? What they are crucial for is not written in these papers—only that there *will* be applications. The utility and desirability of the technologies is implicit.

Three of the papers explicitly argue for the goodness of indium in their technologies. Not only did they study the utility of indium in a particular device, but they recommend their methods. This utility is justified almost exclusively through technical properties of the indium compound or technique, with one mention of low cost in Lin et al. (2019). For instance, Zhao et al. (2019) describes indium selenide as having "record-high charge carrier mobility and photoresponsibity ... [which] can be very attractive for different applications" (p. 1). The results of the study conducted by Kulesh et al. (2020) are purely about technological suitability: "InSb quantum wells are an excellent platform to study quantum confined systems, and particularly relevant in future applications in topological superconductivity" (p. 4). The amount and cost of indium and other materials or the processes and people who manipulate them in these studies are not discussed.

### Experimental process

The process of building and testing devices is described to varying degrees in these papers. Some papers, like Carrad et al. (2020), provide detailed descriptions of each major step in the process, including details like the thickness of deposited layers, brand names of tools, and concentrations of solutions. Kulesh et al. (2020) also provides substantial detail, but uses language that requires significant familiarity with fabrication processes and their devices to readily make sense of. The people who perform the experiments are, by and large, not identified or acknowledged. As is typical of science writing, the experiments are described with in a passive voice, grammatically erasing the presence of the workers.

As mentioned above, wastes produced during the experimental process are barely acknowledged as waste. In a similar vein, the dangers of the processes are ignored. Carrad et al. (2020) describe a step early in their fabrication process as such: "Etching the SiOx using buffered hydroflouric acid (6% in $H_2O$ at room temperature) leaves strips of oxide..." (p. 8). Hydroflouric acid is an incredibly corrosive substance that requires hefty PPE for proper handling. Experimentalists reading this paper know that, of course. Its danger not being mentioned, though, perhaps implies that the danger of the process is irrelevant to whether the results of the study are technologically useful.

#### Acknowledgements

Finally, the acknowledgements sections of each paper gives us some indication of what human labour is professionally acknowledged. All nine papers acknowledged their funders. Lei et al. (2020) received funding from the US Army Research Office; Yuan et al. (2020) received funding from the US Army Research Office and the US Air Force Office of Scientific Research. Four papers acknowledged useful discussions or comments on their manuscripts. Carrad et al. (2020), Lin et al. (2019), Lei et al. (2020), Mazzolini and Bierwagen (2020), and Ovadyahu (2019) acknowledge technical facilities or assistance. A question unanswered by these manuscripts is whether any of the listed authors are lab technicians, whose contributions are routinely under-acknowledged in academic publications and prestige (Barley and Bechky, 1994).

### 3.2.3 Analysis

The institutional practice of physics was already identified as being steeped in colonial extractivist practices. The textual data above shows that this structure also exists at the level of the lab. Let's dig into how land is not represented here, how disorigining is furthered, and how the writing reproduces extractivist logics.

The major elements of land are not written into these experimental articles. The places where materials come from and will go to aren't mentioned, implying their histories and futures are as irrelevant as those places. Discussing indium through its universal qualities, with no mention of, say, geologically imparted impurities, further elides the fact that it came from somewhere. The specifics of how lab workers handled the materials are not included, either. Very few relations are discussed at all.

The absence of this information presents the materials of the experiment as objects which are just as disconnected from the rest of the world as the disinterested practitioners of the science. Their particularities are stripped away.

This is typical of physics writing, and science writing more generally. It is by now a long-established style to speak as specifically as possible about the actions taken in the lab while using a writing style that makes it seem as though the experiment could have happened anywhere (Ding, 2002). This is a feature of science, to many—it is meant to be universal and replicable. Unless local specificities are determined to noticeably impact the results of the experiment, they are irrelevant. So the source of the indium is deemed irrelevant to the writing, because the writing is only about the experiment and its process and results.

By not attending to the places, people, and relations that indium comes from or goes to, physicists disorigin it, continuing the work that mining companies began. They help make it appear as if the indium came from nowhere, or like its origin is completely irrelevant to their work or the consequences thereof. This disorigining is the continuation of work begun by many others to remove the information and physical characteristics of extracted material which connect it to the lands that it is or once was a part of. Like all disorigining, this allows the work to be represented without the cumbersome responsibility to all these relations that indium has.

In place of information about indium's origin or future, readers are offered information about how the technology the researchers are seeking to build is good. The writers of these papers load indium up with value. It is good because of its utility for these technologies, which are also good. It is good also because it has no correlation with significant wastes or dangers. There are no noticeable labour issues in its production or manipulation. The attempt to dissociate from specifics of place is enmeshed with an absence of responsibility, couched in techno-positive scientific and political commitments.

The only relations that the science workers are posited as being responsible to here are the ones where they are compelled to produce more technology. They work to make sure that the indium in their lab works well with their fabrication tools. They shape the way that indium atoms bond other elements of nanocircuitry. They are creating and actively advocating for widespread use of indium-based technology—inserting it further into our technologically mediated relations.

This analysis attends to a particular representation of scientific practice. These articles are professional communication intended for other professional scientific audiences. The analysis thus does not attend to the specifics of each worker who interacts with each bit of indium. They may think differently about this metal versus that one. Some workers worry about working with the hydroflouric acid in the lab. Some workers worry about where all that solvent they used in their fabrication process really goes. None of that makes it into professional scientific discourse.

## 3.3 Connecting the lab back to the world

We have seen in this chapter a long tangled history of physics with tools of violence in extraction and war. The most prominent ethical systems employed in physics were seen to generally be insufficient in terms of acknowledging land or relational responsibility. We saw, finally, that specific practices of physicists reporting on their research with indium in the lab used extractivist logics and participated in disorigining indium. There was little acknowledgement of land in those reports.

There is a simple call here to put land back into physics. In this colonial world, the call for land back is about returning land to the nations it was stolen from. That's a great place to start and an excellent struggle to root this work within physics in.

We will still be working in the material ecological world when the Canadian state is dissolved and the land returned, and so we should still try to connect the lab back to the world. Physicists are not uniform, and certainly not all of them approach their work in a way which continues the legacy of militarized physics or of one which unthinkingly asks for more resources. Many of them are greatly concerned for their future on a burning planet; many of them support Indigenous sovereignty. They are all, as far as I can tell, operating in this broader context in which the cost and effect of doing the science on all parts of land is not considered as an important part of the science.

There is an impetus, then, to know the details of this cost and effect. So, in the next chapter, I will tell a land story about indium. I offer this specifically to the physicists who work with indium in the lab. They are a part of the land story of indium, and in particular of the land stories of the chunks or wires or thin films of indium which pass through their laboratory. In Chapter 2, I talked about how settlers tell land stories about themselves so that they are able to understand the present and act with an orientation toward justice in the future. So knowing a land story of indium might help scientists, who have agency in the way they buy, use, and write about indium, to do so with more responsibility in the structures which have produced it and caused harm in the process.

# Chapter 4

# The connections are deep: a land story of indium

*Out of the chip you can in fact untangle the entire planet...*

Donna Haraway (2004a)

It is clear so far that not knowing where materials come from is a feature of practices of physics. There are many mechanisms at play keeping physics workers in the dark about this, functioning to disorigin the indium at many stages. Physicists further disorigining through their work and writing.

In section 2.4, I wrote about land stories as a way that we can counter disorigining. These stories can take many forms, always focusing on re-figuring a person or place as part of land, in part through untangling the ways that colonial structures have produced that person or place in the way they exist today. They provide information about relations and specificities of place in order to point towards responsibilities. They also emotionally motivate that action.

Here, I will tell a land story of indium, the metal used by all the labs in Chapter 3. If workers in those labs want to counter disorigining, then they must know something about where their materials come from.

I have so far in this thesis made some large claims about the violence of extraction without going into too much detail about what that violence is and has been. This chapter serves as a set of stark and highly representative examples of this violence. Each site and history of extraction is different, as each bit of land is different, but the themes are overwhelmingly similar. Colonizing and capitalist powers exploit people and land, brutally and systematically, all in the interest of profit and power.

Due to the power of disorigining, it is extraordinarily difficult to tell the story of any particular piece of extracted material. At each place it comes to rest, information about its previous whereabouts is erased. Even constructing a specific supply chain is hard. So, here I will look at significant sites where indium is part of the land and undergoes extraction. This partial re-origining of indium cannot provide all the specifics of the relations needed to bring a piece of indium to a lab. Still, when you see a piece of indium or technology that contains it, this story may help you to see some of the places it could have come from, and the structures it definitely came from.

I'll start at the very beginning: indium is made in stars. For us on earth, it comes from rocks. I'll talk a bit about the beauty in that and our need to be specific about being on earth in section 4.1. The richest deposit of indium on earth is in Potosí, Bolivia. It comes from a mine that has been operational for 475 years. Workers at that mine are not paid for the indium that they dig up, but the problem runs much deeper than that. In section 4.2 I will discuss the history of the mountain that used to provide the Spanish empire with enormous amounts of silver through the exploitation of thousands of mostly Indigenous workers and the devastation of entire ecosystems.

Indium ore is processed into a pure metal in smelters. One of the largest smelters of its kind in North America is in Trail, B.C.. This smelter is on stolen land of the Sinixt, K'tunaxa, and Syilx nations. It has dumped enough heavy metals into the Columbia River to create a Superfund site on lands of the Colville Federation of Tribes in Washington. I will discuss this history in section 4.3.

The way that indium is used in technology is an important part of its land story, since devices that we use are also a part of relations. Indium is in so many pieces of technology. Its largest use is in LCD screens, which means you are probably staring through indium to read these words right now. I will talk about this and its other applications in section 4.4.

Future is also a part of land, so the land story of indium in the lab also includes its future as e-waste. Major e-waste processing sites are located in Accra, Ghana and Bui Dau, Vietnam. I'll briefly discuss the social and ecological violence at these sites in section 4.5. I'll finish with some remarks about considering indium out of its original ecosystem to be a part of land, in section 4.6.

## 4.1 From neutron stars to rocky planet

In our universe, everything that is not hydrogen or helium or lithium was formed from the combination of those things inside of stars and during their deaths. Many of the heaviest atoms, including indium, were formed primarily in the mergers of neutron stars, objects that are about 1.4 times the mass of the sun contained in a sphere the size of Manhattan (Johnson, 2017; Ji et al., 2016). Material from these cataclysms ended up in the cloud of gas and dust which would become our solar system.

The earth formed a little less than 4.6 billion years ago. It has held elements comprising almost the entire periodic table in and below its crust for all that time. A truly miniscule portion was freed from the crust to make up living beings. And then we started digging. Not that we've managed to extract an appreciable portion of the earth from itself, somehow. No, we've just managed to turn entire mountains and their ecosystems into rubble, drain salty vibrant lagoons for lithium, and pool toxic waste near the humans who put themselves in danger to break rock apart from rock. So metals, though they were made inside of stars, come, for us, from the crust of our planet.[1]

We are fairly disconnected now from the neutron star mergers that produced indium in the first place. We live on the earth that holds that indium. As I will discuss in more detail in Chapter 5, everything we do is part of the earth, not merely the universe. Metals are part of land. They make up rocks. Indium is usually part of zinc and copper ores. They dissolve into streams. Many of them are crucial for functions of life; many are toxic to it. Geodiversity contributes significantly to biodiversity (Fox et al., 2020). The rock is where it begins.

## 4.2 Pleasant Mountain // Mountain of Riches

In south-central Bolivia, there is a mountain named Sumaq Urqu—pleasant mountain in Quechua. The area is dry but not arid; some neighbouring mountains are dotted with small trees. Sumaq Urqu used to look like that, too. Actually, the whole area used to be forested. Then the Spanish came in 1545 and found silver. They called the mountain Cerro Rico,

[1] Once I googled "where do iPhone materials come from" and Google showed one of those little info boxes that had in big letters, "Holes in the ground".

Figure 4.1: Sumaq Urqu or Cerro Rico. It used to look more pleasant. Mhwater at Dutch Wikipedia [Public domain].

mountain of riches, and started cutting down trees.

For the next fifty years, the ore pulled out of Cerro Rico would dominate silver production—more than 60% of all silver produced in those decades came from that mountain (Flynn and Giráldez, 1995). In fact, the mountain holds the largest known deposit of silver on the planet (Cunningham et al., 1996). The city there, Potosí, became one of the largest in the world, with a population of 120,000 in 1573. That was larger than Rome, Paris, or Madrid. It was the centre of colonial wealth in the Spanish empire. Over the next decades, production waned and waxed as the quality of ore declined and smelting technologies eventually caught up.

The Spanish colonists were not the ones who pulled their wealth out of the ground. Indigenous people from a wide area colonially known as the Viceroyalty of Peru worked the mines. At first, miners dug and refined silver ore with some degree of freedom, selling it into a Spanish-controlled market. As the quality of ore decreased, miners refused to work, so the Spanish empire began the *mita*, a conscription effort that forced Indigenous workers to use the new technology of mercury amalgamation to refine the poor-quality ores (Bakewell, 1977). The resulting damage to the structures of life was broad and devastating; as Moore (2003) says, "there was no technological fix to the new regime's ecological contradictions" (p. 337). Massive dams were built to power new mills which crushed ore. The collapse of the main dam in 1626 killed hundreds. The mercury came from a mine in Huancavelica, a few hundred kilometres southeast of Lima, which deforested the mountains for tens of miles around. In fact, mining operations in South America deforested a suprisingly and devastatingly large area of the continent. Looking at Sumaq Urqu today, it seems ridiculous to suggest that it was ever lush, but "when it was first discovered it was fully covered of trees" (Moore, 2003, p. 338). At Huancavelica, workers carried unreasonably heavy loads, worked in flooded passages, and were kept underground sometimes for six days in a row. Mercury poisoning was common not only in workers but in their families. Mercury from the Huancavelica mine and the silver almagamation in Potosí was dispersed into the environment at a rate of about 300 tonnes annually for sixty years around the turn of the 17th century. This was redistributed to living beings through water and fish. Disease was rampant amongst communities of travelling, exhausted workers. More than *half* of the people in *mita* communities died between 1581 and 1609 (Moore, 2003, p. 346).

The extraction of silver was a massive force in shaping the land of Potosí. Spanish-mandated extraction and forced labour changed the face of South America in extremely deep and violent ways. The Spanish built their empire on this silver & violence.

475 years after the mining of Sumaq Urqu began in earnest, the mountain is still being mined. Miners still die. It has a newer name these days: the mountain that eats men

(Shahriari, 2014). The people who mine it are still mostly Quechua. They work together in co-ops and are relieved of responsibility and the ore's profit once they sell it to local mills (Francescone, 2018). This is part of the colonial structures which ensure that anything that can be extracted from this mountain and the people who live with it mostly goes towards the benefit of colonial powers.

Among the silver in the mountain is (or was) also substantial amounts of tin, antimony, lead, zinc, and many more trace elements. The rock of and under Cerro Rico is likely the richest indium deposit in the world. Indium generally occurs with zinc ore and is always a trace element. Even this, the richest deposit in the world, is about 0.0012% indium.

Bolivia has a reputation among people who trade large amounts of metals as an important source of indium. But somehow the people who mine it don't seem to have gotten this memo or any of the related cash. Francescone (2018) investigated indium mining in Potosí and found that miners weren't being paid even by local mills for the indium content of their ore. When workers take ore out of the ground, they visually analyse it for metal content and sell to the mills based on this analysis. Indium and other trace metals are too sparse to be visible. Mills do a first stage of refining which does not separate trace metals out. They sell concentrates of zinc, silver, and lead to smelters outside of Bolivia that have the facilities to refine metals to extremely high purities. Smelters in China, South Korea, Canada, and Japan who buy concentrates from Bolivian mills are well aware of their likely high indium content. They choose to pay no mind to that fact when paying the mills.

The lack of high-grade production facilities inside Bolivia is one manifestation of corporate imperialism. By only paying workers in Bolivia for "raw" resources, jobs and profits produced at other stages of manufacturing are hoarded by wealthy countries (Girvan, 1976). This is intentional. Not only do the people of Potosí endure most of the intertwined health and environmental devastations, but they also see the smallest portion possible of the capital gains produced. In a previous article, I noted that "multi-national corporations and Northern states have sought to ensure the people of Bolivia cannot take production into their own hands, let alone control its fate outside the strictures of production" (McKay, 2020).

So, a place that provides a large amount of the indium-containing ore in the world is a place that has had its geological, ecological, social, and economic structures and relationships shaped by the logic of colonialism and extraction for almost 500 years. These relationships and their logics are marked by violences that happen at different speeds. There's the immediate violence of brutal forced labour, the removed kind of violence that kills fish by mercury poisoning, the slow but neverending violence of forever removing a mountain's ability to grow trees. It is not that there are no other kinds of relationships in Potosí; no, people have creatively resisted extractive logics for as long as they have existed. But it is the case that we would not have indium shipped out of Bolivia if not for these violences.

## 4.3 Sinixt tum-xula7xw // Trail, British Columbia

Where does indium go from Sumaq Urqu? We can't say for sure for any batch of concentrate. We do know that Bolivia is the largest single source of indium on the planet and that China, South Korea, Canada, and Japan are the biggest producers of refined indium (USGS, 2019). It seems like a safe bet that smelters in all of these locations purchase Bolivian concentrate. I live in Canada, which produced 9.2% of indium in 2018 (USGS, 2019). A few years ago, I lived in the Kootenays in British Columbia. There, I sometimes passed a large smelter in the town of Trail. I also learned about the Sinixt, a nation whose land the many towns of the Kootenays are on, yet one which is not even acknowledged by the colonial Canadian government. Teck Resources Limited owns that smelter. They don't publish information about where their indium comes from, but some indium from Bolivia is very likely to have passed through its fires. Let us see, then, how colonial extractive logics have also shaped the land at the smelter to turn it from Sinixt tum-xula7xw (territory) into Trail, B.C..

The traditional territories of the Sinixt, Syilx, and Ktunaxa nations are large and overlapping, in what is now mostly known as southern interior B.C. and northern Washington state. As colonists established themselves on the eastern part of the continent, more of them wanted to move west, to ever more resources and power. In 1763, however, King George III issued a proclamation that made settling anywhere west of the Appalachian Mountains—almost all of modern day Canada—without a treaty illegal in the eyes of the British crown (Hill, 2011; Aldridge, 2015). This proclamation was one of the factors that led Americans to revolt, but it doesn't seem to have presented as much of a problem to settlement as they feared: essentially all of British Columbia was settled without treaties. The 1875 B.C. Lands Act was an attempt by the provincial government to legally bypass the need for treaties. It was struck down by the federal government, but the 1876 Indian Act quickly came to the rescue. Under the Indian Act, a horrifically colonial piece of legislation, the federal government acts as the ward of all Indigenous people, removing their ability to act as members of their own nations and undermining the nation-to-nation imperative of the Royal Proclamation of 1763 (Hill, 2011).

So settlers went to the land and called it British Columbia. They started in Vancouver, mostly, and worked their way inland. For many, they were drawn by the promise of gold, and then by zinc, lead, and coal (Mouat, 1995). In the late 1700s, as settlers moved inland, the Sinixt were a strong and populous nation. They were then decimated in population by a smallpox epidemic (Pryce, 1999). Still, they retained political strength and resisted appropriation of their lands by miners and other settlers at several turns (Pryce, 1999; Wilkinson and Sutherland, 2012). The colonial border between the U.S. and Canada divided their lands and their rights under the occupying governments. The Sinixt had a close relationship with the Colville nations, and part of the Sinixt joined the Colville on a reservation in Washington state, established in 1872. Many remained above the colonial border at least for a time and were also known as the Arrow Lakes Tribe. Decades of poor treatment encouraged some to move south, though. In 1956, the federal government declared the Sinixt extinct, removing the ability of any Sinixt person to claim certain rights under the Indian Act (Sinixt Nation, nda). This has since been heavily criticized by Sinixt nation members who live above the border.

The town of Trail was established in Sinixt tum-xula7xw around the smelter and the mines in the area in the late 1800s (Mouat, 1995). The man who founded the smelter, Fritz Heinze, simultaneously bought the local paper in 1896 (Mouat, 1995, p. 27). Over a century later, the deep relationship between town and smelter is still strong, with the mayor quoted as saying, "Teck is Trail and Trail is Teck" (Canadian Press, 2012). It is clear that dispossession established the smelter and the town, and that the town's purpose was to maintain the operations of the smelter to generate wealth primarily for those who own it.

The presence of the smelter has significantly changed the land. From the founding of the smelter in 1896 to 1995, its operators released over 12 million tons of slag filled with heavy metals into the Columbia river (Parrish, 2005, p. 371). On average, that's 400 tons per day of particulate matter chock full of arsenic, lead, and zinc. In 1994 alone, the smelter released more copper and zinc into the river than *all* American companies were allowed to release into American waters for the entire year (Parrish, 2005). Much of this sediment settled in Lake Roosevelt, an artificial reservoir above the Grand Coulee Dam located on the lands of the Colville Federation of Tribes, some 150 km south of Trail.

In 2003, the American federal Environmental Protection Agency (EPA) asked Teck to participate in action to investigate and remediate the Columbia River site on Colville Federation lands under Superfund (CERCLA) legislation (Hess, 2005, p. 4). A back-and-forth ensued, as it is not usual for American legislation to apply to a Canadian corporation. The Canadian government sent memos to the US Department of State and they were sent memos back. The Colville Federation successfully brought a civil suit under CERCLA against Teck in 2004. They sued for Teck to follow the EPA order for remediation and to recoup the cost of responding to the crisis, including costs for healthcare and "damages for injury to natural resources" (Hess, 2005, p. 23). After 14 years in court, the Ninth Circuit Court of Appeals rejected an appeal from Teck, landing them firmly with the ruling that they were to provide 8.25 million USD to the tribes (EMJ, 2019; Indianz, 2018).[2]

Now, the Colville Federation has recouped their legal costs. Teck is to be held responsible for cleanup, estimated at 1 billion USD (Indianz, 2018; Canadian Press, 2012). It is not clear that this will happen quickly; it's not even clear that the river *can* be 'cleaned up'. One of the many injustices of the mining in South America is that the mercury lost

[2]This is an interesting precedent for those who would like to take the extractive industries to court. The EPA is an American agency and Teck is a Canadian company operating on land illegally but successfully claimed by the Canadian state. CERCLA explicitly applies to storage facilities located in America, and arguing that Teck intentionally 'stored' toxic materials in the river was the key to getting them into court. There is ample discussion from Parrish (2005) and Hess (2005) about the method of using the laws of one country to restruct activities in another. It is, in many ways, imperial. International treaties have been used before to negotiate cross-border environmental disputes. In fact, in 1909, Canada and America signed the Boundary Waters Treaty, which includes the provision that "waters flowing across the boundary shall not be polluted on either side to the injury of health or property on the other" (U.S.-U.K. (1909), quoted in Parrish (2005)). This treaty has not been used in international negotiations in decades.

while amalgamating silver entered into the ecosystem, unable to ever be recovered. Here, again, mercury and other toxic atoms float in a river which used to provide food for nations. Fairchild et al. (2012) provide evidence that toxic sediment decreases life expectancy of white sturgeon even when it is settled at the bottom of the lake, as sturgeon begin their lives in the sediment. They suggest uncontaminated sand could be added on top of the toxic material in Lake Roosevelt, but caution that interactions of contaminated and uncontaminated materials are not well understood. Numerous studies also show that toxic metals in rivers decrease life expectancy of salmon (Balistrieri et al., 2018; Svecevičius et al., 2014). Most salmon extirpation in the Pacific northwest has been caused by dam-building, but salmon populations have also declined in areas that are still accessible to them. In 2004, a member of the Colville Federation shared this about salmon populations: "You hear stories from the elders of how the [Columbia] river used to be and Kettle falls being able to walk across the river on the backs of the salmon. Now... they are afraid to eat the fish" (Parrish, 2005, pp. 374–375).

The Sinixt Nation Society, based above the colonial border, write that the loss of salmon was "comparable to when the Plains People lost the buffalo" (Sinixt Nation, ndb). In 1994, the state of Washington advised that people not salmon in the Columbia River due to mercury (Parrish, 2005, p. 373). Yet salmon are a keystone species, cycling nutrients from the oceans to the forests and their people (Rahr, 2011). Value extracted from their decimation via the smelting of metals is now directed towards an attempt at 'cleaning up'.

Teck also pollutes closer to home. The residents of Trail are subject to lead dust in the water and soil. In the 1970s, blood lead levels in children were massive, with 40% of children aged 24 to 72 months over 15$\mu$g/dL. This slow violence against the people doing and supporting the work of seaprating metals from each other continues to this day.

Teck refitted the smelter in 1997, reducing the amount of indoor lead dustfall in the region by a little more than half (Hilts, 2003). The Trail Area Health & Environment Program, operated by Teck, talks up the success of this program and associated efforts at testing and replacing topsoil in the community (THEP, 2011). None of this has been accompanied by making amends to the community by distributing its wealth. Blood levels are still 2.9$\mu$g/dL in children six to 36 months, as of December 2019, more than twice the Canadian average (Regnier, 2019). The CDC maintains that no level of lead is safe (CDC, 2019).

Teck produces bars of high-purity indium among a host of other metals in Trail. As in Potosí, the existence of their smelter has depended on colonial usurping of land and the extraction of resources through the inflicting of toxic violence on that land. The production of indium from ore to bar is made of violent extractive relations.

## 4.4 Indium in technology

How does indium get from a smelter to the lab? Recall that it is a valuable piece of market information to know the exact structure of a supply chain. So, suppliers are kept secret, and it's very difficult to discover what smelters retailers purchase from. Of the physics papers reviewed in Chapter 3, only Lin et al. (2019) made a note of what company they purchased their metal from. So, without interviewing lab workers, I don't know what companies they make their purchases from.

So, what *can* we say about indium after it leaves relations at places like the Teck smelter? After any geological markers of its origins—its 'impurities'—are smelted away, high-purity indium is sold in large quantities to retailers. I do know some of these retailers: Sigma Aldrich and Indium Corporation of America are among the largest. These companies form it into bars, or wires, or tiny balls, or powder, or melt it with arsenic, or oxidize it, or prepare it one of some dozen other ways, and sell the indium to manufacturers and labs.

The technologies that indium ends up in are also arguably a part of land, because they shape relationships. And knowing these technologies can help us to know what it is we are asking to leave behind when we ask for the reduction or dissolution of extractive practices. So, what is it used for? We'll start by reviewing applications that are well-established, large draws for indium consumption, and then revisit some of the papers of Chapter 3 to discuss uses in the lab and possible new large-scale technologies.

The single largest use of indium in the world is as a thin-film coating of indium tin oxide (ITO) on LCD and other screens due to its transparent and conductive nature. It accounts for 75% of global consumption (Chancerel et al., 2013). There are a few important things to note about this application. First, it had a temporary but significant effect on the price of indium, which had been fluctuating in the 100–300 USD/kg range in the 80s and 90s (Survey, 2015). In 2005, the price reached a peak of 946 USD/kg. It has since fallen back down. The demand for indium was significantly affected by the new technological application; its production increased by 1377% between 1973 and 2013 (Frenzel et al., 2017). A material being valuable on the market is also the key to justifying opening a new mine—far more of an influence than the environmental safety or the actual need for more of a metal in the world. Now, indium is never the primary metal of a mine, since it occurs in such small quantities and usually in the ore of a more plentiful and valuable metal like zinc. But increasing the financial gains of large mining projects is not a great strategy for getting them to stop their operations (a goal which is reasonable for any life-abiding climate strategy). Indium is considered a critical metal in the EU and the US. These materials are those which are not only deemed crucial for the function of the economy and military, but which are subject to various supply constraints (Ylä-Mella and Pongrácz, 2016). Strong policy decisions can and will be made to secure the supply of these critical materials (Carpenter, 2012; Slowinski et al., 2013, e.g.). Another important thing to note about this application is its ubiquity. LCD screens surround us, with at least a few gracing almost every home in wealthy countries. I am currently writing my thesis on a laptop, staring at these letters appearing on a screen when I press buttons with my fingers. You or your screenreader are almost certainly reading these words on a screen—if not, you probably used one to print them out. Yet there was a time before screens. So indium, in the form of ITO, has shaped our lives in addition to stock markets and ecosystems.

A thin film coating on LCD screens may be the single largest application of indium, but there are dozens more ubiquitous ones. For how rare it is, it is surprisingly broadly used. Indium is considered a crucial metal for circuit architecture, largely in indium phosphide semiconductors. Indium gallium phosphide also forms the central element of many LEDs. Its other applications range from vacuum sealing in high-vacuum environments to an element of alkaline batteries to dental fillings. ITO is also used in a wide range of applications, including as a coating on airplane cockpit windows that defrosts the windows when a current is run through it (Indium Tin Oxide, 2020). One of the earliest uses of indium was in ball bearing systems in weapons.

In Chapter 3, I reviewed nine recent scientific papers that make use of indium in the lab and showed how they participated in the disorigining of the metal. Their scope provides a good overview of some of the major interests in using indium in a lab for new technologies and for 'fundamental' research. Indium is already used in circuits, and it is widely used in nanocircuitry and nascent superconducting architecture for quantum computing. Work such as Lei et al. (2020), Carrad et al. (2020), and Yuan et al. (2020) seeks to refine and expand the utility of indium in such applications. Kulesh et al. (2020) use indium for quantum dots, another type of architecture some hope will be used for quantum computing. Lin et al. (2019) are, in fact, still working on displays, but this time for the organic LED backlight of one. Zhao et al. (2019) argue quite strongly for the utility of indium selenide in flexible electronics. Sahoo et al. (2020) uses indium as a case study for investigating nuclear structure, which they don't tie to any technological application, but may have one yet. Finally, Ovadyahu (2019) and Mazzolini and Bierwagen (2020) contribute to materials science literature on the properties of indium in thin films and nanofabrication. Applications like superconducting quantum computing architecture are not widespread at the moment, to be sure, but they are spoken about in grant proposals, article introductions, and mainstream media as if they will be. In trying to shape our relations with new technology, scientists and other tech workers are implicitly relying on the relations of extraction. Every new use of a metal that we deem to be fundamental tightens the bonds of our lives to these relations—makes our relations more extractive.

This is where a significant nexus of choice lies. Since we made choices to bring these things into the world, we can arguably choose to take them out again, or at least lessen their ubiquity. Once we acknowledge extraction as violent, what other kind of approach can we take? The potential for new technologies which further increase demand for indium, which will only ever be extracted through violence, is a potential for increased violence. We will revisit the possibility of power through making choices about technology and labwork in Chapter 6.

## 4.5 Indium, wasted

You have, before, gotten rid of an electronic device. Where did getting rid of it put it? You don't know. I don't know. But we both know that it didn't just disappear. Just as everything we have ever touched came from the earth, almost nothing on this planet will ever leave it. E-waste is a word for electronic objects which are deemed beyond use.[3] After billions of years in the crust of the earth, metals are violently ripped from it and formed into complex devices through the labour of human hands only to be considered... waste? Surely we must have made a mistake.[4]

Yet this is our reality. 50 million metric tons of material called e-waste is collected annually and that number is only expected to rise (World Economic Forum, 2019). Where does it go?

The human and environmental effects of pollution from e-waste is a primary subject of deep investigation in discard studies and media archaeology. Gabrys (2011), for instance, dives deeply into the natural history of electronics, aiming to make the materiality of the virtual visible by attending to what it leaves behind. LCD screens and trashed qubits are no exception. As objects and as elements of waste management structures, like shipping containers full of e-waste or poorly ventilated shacks where solvents are used to strip gold out of circuits, bits of discarded indium are another spot from which to view the relations that make up global extractivism.

E-waste itself is extractive. Piles of discards take up space. They leach chemicals into the ground from broken batteries and the wear of time. When e-waste is processed, it is

[3] These objects are also sometimes called WEEE, as in waste electronic and electrical equipment, an acronym which is far too fun for the subject matter.

[4] Or several.

done by people, and usually by people again with minimal access to PPE, safety standards, and healthcare. Recycling isn't clean. The solvents they use are also waste. The smoke from smelting is also waste. But it doesn't go elsewhere; there is no elsewhere (Liboiron et al., 2018a). In polluting people and place, space and health are extracted for the value of being able to discard 'waste'.

Since ITO on screens is the main use of indium, efforts to reclaim this metal from e-waste have focused on these thin films, with at least half a dozen processes for doing so (Ylä-Mella and Pongrácz, 2016). Still, indium is recycled at a rate of less than 1%.

There are many places to attend to, here—places in Vietnam and Ghana, for instance, where people have been forced by global economic structuring to take up dangerous work in order to survive (Oteng-Ababio, 2012). We know that there is significant entwined social and environmental impact at these sites. Workers in Accra, Ghana are poisoned with arsenic, lead, and tin (Asante et al., 2012). The rivers in Bui Dau, Vietnam are full of flame retardants (Matsukami et al., 2015). The reasons that these sites are more polluted than others have everything to do with hundreds of years of violent colonial relations.

Yet we won't attend to the specifics of these relations here. I regret this, as I know that discarded indium is just as much indium as any other piece is. And every piece of not-yet-discarded indium is likely to end up as a part of the network of relations of a waste site at some point.[5] Waste and its co-constituting relations are part of the land story of indium. I hope to attend to it in more detail in the future, when it is not so easy for me to cry when reading a story about the world. Maybe after COVID-19, when the air is not stiff with grief and violence, I will have more space to witness in detail the extractivism of LCD screens baking in a pile in Accra. Probably I will attend to it sooner than that, because this

[5] Though it is true that a great portion of consumer electronics which are no longer in use are not in waste streams; perhaps 75% sit in drawers, resisting removal (Gabrys, 2011, p. 2).

grief, like that of a dying planet, will linger for a long time.

I am not trying to witness and explain in order to end up a mess on the floor of my apartment.[6] I am working to witness productively. Much of the point of a land story is to come to know specifics; to be able to look at a piece of technology and re-constitute some of the relations that made it, and some of the relations that were broken to make it. But even if we are familiar with a million details of a particular atom of indium, the land story means little without a land ethic. If the story does not move you, there is no point to the story. If the story moves you deeper into depression, there is little point to that either. Sobbing, though sometimes necessary, does little to improve the world, least of all our own. There is sufficient information here about e-waste to add to our picture of the land that is indium, of the indium that has passed through land. It is enough to know that discarded indium continues to be a part of relations of violence against the structures of life.

## 4.6 Limitations & the persistence of land

Like how land stories about human ancestry are specific histories of colonialism that illuminate more of the whole and motivate us to anti-colonialism, this story about indium is a particular history of colonial extraction, intended to motivate those working with indium to anti-extractivism. Here, we have seen that Spanish colonialism in the 1500s responsible for the deaths of hundreds of thousands and the devastation of ecosystems paved the way for indium mining in Potosí today. Indium is smelted by Teck, a corporation that exists only because settlers stole Sinixt land, and which has devastated the Columbia River ecosystem. We are in relation with indium every time we use a screen. And it ends up somewhere,

[6]Thanks to Simon Daley for his help with getting me off the floor and moving forward, and to Ezra Teboul, David Paton, and Carolyn Earnest for help articulating this point.

where it may be recycled, or where it may sit in a pile of electronics slowly leaching toxic chemicals.

There are many limitations to in this land story. It is not the specific story of a particular wire of indium; it is not the story of the indium in the screen I am writing on. I wish it were. As I've argued, the structures of disorigining prevent that story from being told.

I spent little time with the geological properties of the ore indium is found in and how those properties were a part of Sumaq Urqu and geodiversity generally. I didn't spend much time with the chemical properties of indium, with what makes it as an atom useful for all of its many applications. I wasn't generous to the use of ITO in screens, though there is little doubting that screens have made the world lively in many ways. I spent little time with the people who work the smelter and the mills and none at all with the people and the ships that transport material from South America to North. I didn't talk much about e-waste or the people who deal with it or the people who profit from it or the possibilities for recycling. And there are few *very specific* relations discussed here. I have attended to long histories and big actions instead. The opportunity to be responsible often shows itself, though, in the smaller, more specific relations.

I have shown that indium in the lab is clearly a part of extractive networks; but how is it a part of land, even when it has been extracted? Is it still a part of Sumaq Urqu, even when it is no longer geologically or chemically identifiable as such? Dylan Robinson wonders similarly in *Structure for acknowledgement*, sitting in a building made of limestone mined from stolen Haudenosaunee and Anishnaabe lands, "trying to hear if these walls are also still the land" (2019). I do not have a definitive answer to this question—I am not the authority on what does and does not count as land. But I will make some suggestions.

The ontology of land is one of relations. Land is made up of relations between nations, say, in a Haudenosaunee frame. We often think of relations in terms of synchronicity and reciprocity—as in, one can only have relations with other beings who are around and who respond to you as you do to them. Reciprocal relations are not the only kind, though. Beings with more power or beings long dead often have huge impacts on our lives. Is this not a relation? Looking in this way adds more depth to what it means to be 'a part of'. Indium from Sumaq Urqu will always be indium from Sumaq Urqu, even if we cannot tell, even if it makes no difference to the properties of the indium or the screen that it is in. Dumit (2014) asked how this is possible or how it manifests: "How do T-shirts, croissant, and pencils contain their histories without our being aware of them?" (p. 345). I have talked about how our not being aware is from disoriginining. The history being contained in the object is exactly this relation: without Sumaq Urqu and the people who mine it, it would not be there. So it will always belong to the mountain and its people.

This addresses a bit about responsibility, too. The Spanish did not rend Sumaq Urqu open for indium, nor was the smelter at Trail built to produce it. If we nonetheless view this history as describing a causal relationship, then we can see the responsibility of those who benefit from indium production in addressing the harms, instead of writing indium off as a side benefit from the 'main problem' of silver mining.

Another way that indium seems, to me, to still be a part of the land of Sumaq Urqu (and all the other places that it has had or will have relations) is in the way that it is no longer. It is clear that the indium having left the geo-ecosystem en masse is a sign of the violence that remains behind it. Possibly, the indium holds a mark of grief for the loss of the relations that it once supported on a mountain which used to be pleasant—a grief for the change of those relations into ones which treat the mountain like it is made of wealth.

Perhaps there is a way to repair some of that which has been broken; if the trees are able to come back, and the people are safe, and the tailings are maintained apart from everything else forever. If the relations are made good, the grief could be lessened. But we don't tend to give rocks the credit they are due for being an active part of relations, though they are a slow-moving, difficult-to-see part of them. The ground is where life happens (Fox et al., 2020). Rocks are made over millions and billions of years. Humans can't fix them. And we cannot fix the fact that this violence has been killing and disabling people for centuries. Some grief in our world cannot be lessened.

This chapter has been about indium but indium is not unique. The wealth of the world (the wealthy part of the world, that is) is largely built on extracted materials and the violence it takes to remove them from the ground. As we will see in the next section, even the triumphs of physics depend on extraction. This fact must move us beyond a land story; it must move us to action. We will revisit the power of refusal and Luddism to counter the violence of extraction in Chapter 6.

# Chapter 5

# Physics phenomena are land, too

*Without validating mind with ecological properties, there develops educated minds engaged in diminishing global ecological integrity through the exercise of chronically overdeveloped reason.*

Joe Sheridan & Roronhiakewen "He Clears the Sky" Dan Longboat (2006), p. 373

Let's recap a bit. I have shown that the activities of physics are deeply connected with extraction, which is colonial. To do that, I discussed the history of physics, its deep support of imperialism through weapons development, and how dominant approaches to ethics avoid questions of resources and environmental responsibility. I showed that though physics writing ignores it, experiments depend on vast structures of extraction which have been enacting violence against the structures of life for hundreds of years. All of this supports the point that the *activities* of physics involve the fruits of extraction and that they do so in a way that upholds and benefits from global extractivism.

In this chapter, I would like to push this argument further. I will argue that the objects of study of physics are, in fact, a part of land, addressing my second research question. Stars and quantum fields perhaps share little ecological context with us, but it is through the cultural-material practice of physics that these objects are made into objects. This places the objects of study of physics firmly and specifically on earth, rather than in the more typical larger and less specific context of the universe. Since the practice of physics is unavoidably landed and extractive, so are the objects of study of physics. To do so, I will use Barad's concept of a phenomenon as the basic ontological unit.

Barad's work is a pillar of new materialism. They take their interpretation of quantum ontology and use it to inform an ontology for the whole world. In their framework, there are no hard boundaries around the physical and discursive elements involved in any particular phenomena, exemplified by the importance of a cigar in the results of a classic physics experiment. My main purpose is to use this framework to argue that phenomena could not happen *as objects of study of physics* without the extractive networks that brought materials for experiment and computer to physics workers.

Barad's framework is not emplaced; though they attend to specificity, they make far more reference to being in the universe than to being on earth or in a particular place. The way that they prioritize an ontology of quantum physics serves to reproduce assumed epistemic authority of physics, which isn't necessarily more valuable than an ontology based on culturally specific ecology. Before making use of their framework, I will advance a constructive critique of it.

I will start with summarizing the framework in section 5.1 before critiquing it in section 5.2. I will make my constructive argument in section 5.3 and conclude in section 5.4.

## 5.1 Barad's phenomena

In *Meeting the Universe Halfway*, Barad presents an ethico-onto-epistemology based in quantum mechanics. They cover a lot of ground, and I don't intend to present their entire framework of agential realism here. One might say, actually, that I am making use of their analytic mode of *diffraction*, taken from their experience as a physicist and from Haraway, who notes that "diffraction patterns record the history of interaction, interference, reinforcement, difference" (Haraway, 2004b, in Barad, 2007, p. 71). I am focusing on Barad's notion of a phenomenon not to reproduce it exactly in this text but rather to write it as I understand it and to write it expansively, differing from the way I read it from Barad.

So, what is a phenomenon? We can start from the world, which is made up of matter. Speech is matter, discourse is matter—because they all exist within the universe and have causal effects. There is no hard line between what is natural and what is cultural. In fact, there is no hard line between anything. When bits of this world interact together, or 'intra-act', differences are produced between them that allow their distinction. An intra-action requires some kind of apparatus, which includes the bits of matter intra-acting, any people who set them up together, the discursive framework that might have encouraged their setup, and of course any physical tools involved. Through all of this differences are made legible and individual objects are made.

Let's get more concrete to get closer to the point. We can think, for instance, of a classic pesky problem of quantum mechanics: wave-particle duality. When you run an experiment one way, you get a result consistent with a wave. Run it in just a slightly different way and you get a result consistent with a particle. To many, this indicates a *problem*. Is the object in question a particle, or is it a wave? How can it be both? But this is only a problem if you run the experiment expecting to measure something which *already exists*. Of course, there is *something* with which the experimental apparatus interacts. And it's the same something whether you use the experimental apparatus that makes it look like a wave or like a particle. The thing that changes is the apparatus. You measure that something in a different way. The word 'measure' doesn't serve us well, here, since it seems to imply the something already has the property we want to observe. In reality, the apparatus intra-acts with that something to produce a phenomenon which is legible as the result of a wave (a diffraction pattern of lines on a screen), or, a different apparatus intr-acts with the something to produce a phenomenon legible as the result of particles (two bright lines on a screen).

Rather than there being an object of study of physics that *is* a photon, there is a setup of metal and laser and screen that produces something we can see: "*theoretical concepts* are not ideational in character; they are *specific physical arrangements*" (Barad, 2007, p. 109, emphasis original). When I write, here, about an object of study of physics, or about a phenomenon in physics, this is what I mean. It is a setup that materially exists that allows some bits of the universe to interact with other bits of the universe and to be read in a way that allows us to say one of those bits behaved like a particle, or was highly entangled with another bit, or that a star is so many billions of years old, or that the composition of some shaking rock includes natural-gas-rich shale.

Photons are not something that exist 'out there' in the universe. We do have good evidence that suggests matter behaves in impressively spatio-temporally uniform ways, which means that if we use the same apparatus in a different time and location, we'll get the same result. There is *stuff* that really does exist. The stuff that interacts with a lab apparatus in way that is legible as a photon interacts with other apparatuses in similar ways, but not in the ways that it interacts in the lab. This way is as stuff under study, as stuff to be controlled, and as stuff which serves to control other bits of matter. Experiments involving photons are a particular material-discursive setup creating apparati that do not exist elsewhere. In this sense, photons *as physics phenomena* do not exist outside of the practice of physics.[1]

The apparatuses which produce phenomena are a crucial part of the phenomena. Here is the point about phenomena that we really need to do work in this chapter: there's no hard boundary around what counts as the apparatus. The apparatus is made of all the stuff that is causally involved in the phenomenon. So, the *actual properties* of a particular photon—its momentum, say—depend on the entire apparatus that measures it, including the funding structure that put the avalanche photodiode on the table and the hours of alignment that a graduate student put in to the optical setup. I will use this to argue that land and the extractive structures exemplified by the story of indium in Chapter 4 are a part of physics phenomena. To get there, I first need to refine Barad's concept.

## 5.2 Dethroning physics & working with land

There are two major problems that I see with Barad's work. First, by privileging the explanatory power of quantum mechanics, they uphold a widespread presumed epistemic authority of physics. That authority is a problem, since it serves as a justification for the necessity of practicing physics, even when the practice of it causes harm. Second, and related, by talking so much about the universe, Barad misses the importance of land. They act as if quantum ontology gives us a new way to think about relational ontology when

[1]It might look like I've created a sharp divide, here. I am not trying to do that. I am not interested in the boundary between what counts as a photon as a physics phenomenon and what doesn't. I am only trying to show that there *are* specific contexts created by the social and material efforts of physics which display or contort bits of the world in particular ways.

Anishnaabe and Haudenosaunee thought have been doing it for a long time. I am seeking here to use both Barad's phenomena *and* land together to argue that physics phenomena are landed in a way that disrupts the presumed necessity of physics.

### 5.2.1 Quantum mechanics isn't universal

Barad works from explicit examples of quantum mechanics to make claims about the whole world. They use the literal language of entanglement—a quantum theoretical word—to describe the enmeshed nature of matter that intra-acts in a phenomenon, no matter what size or temperature it is.

Quantum theory is rich and powerful, yet it will never be a theory of everything. The way that Barad writes encourages the reification of quantum mechanics: the view that it, somehow, gets at what is most true about the world. This elides many of the specifics of the dynamics of matter, society, and ecosystems. This treatment is not emplaced. As discussed earlier in the thesis, it is important to attend to the specifics of place—not just the universe at large. Hollin et al. (2017) raise a related critique of Barad, using Anna Tsing. There is no such thing as a universal scale, no universal critical phenomena. Why would there be particularities in every interaction yet universality across scales? Tsing (2017) requests, instead, that we pay attention to friction between different scales of the universe.

There are a few frictions between the scale of the quantum mechanical that Barad uses as their defining examples of phenomena and the scale of ecology: the non-existence of entanglement at a large, wet, warm scale, the highly contextual nature of quantum theories, and the ability of bits of earth to be historied in ways that electrons aren't. Overall, this supports a fourth problem: quantum theoretic language being widely used in a way that is uncritical of and thus further entrenches the role that quantum mechanics itself has played in supporting colonialism and extraction.

### Entanglement is for quantum stuff

Barad argues that, because quantum physics provides us with accurate results at a range of scales from the microscopic to the macroscopic, it supersedes classical physics (2007, p. 110). They acknowledge that classical mechanics is still more useful in, for instance, projectile problems, but that we know, fundamentally, that quantum mechanics is the correct framework which describes the dynamics of the entire universe.

The theoretical basis for their argument is that Planck's constant, $h$, is nowhere zero. It is, as far as anyone can tell, $6.626 \times 10^{-34}$ Joule seconds, everywhere in the universe. This constant sets the scale of the fundamental limitation on measuring position and momentum (or other complementary variables) and much else besides. Roughly, to get classical mechanics back from quantum mechanics, you usually take the limit of $h$ going to zero. This is well-justified for classical mechanics, since for large objects, the ratio of $h$ to the mass $m$ is very tiny—close to zero. Or, for very warm objects, the ratio of $h$ to the average energy of a particle is very tiny. Yet it never is *actually* zero. So, says Barad, classical mechanics is strictly wrong and the only reason we don't use quantum mechanics everywhere is an effectively technical limitation of the difficulty of using it for many calculations. And, finally, we thus have reason to believe that there is literal entanglement at macroscopic scales.

But entanglement is a specific property of quantum information. It is just a measure of correlation.[2] Correlations in quantum mechanics can be much stronger than those in

[2] Barad would probably dispute this. Their interpretation of quantum mechanics is ontological, meaning that they attempt to take the metaphysics suggested by the theory as literally as possible. Many quantum theorists take an epistemic interpretation of quantum states, meaning that they take the quantum state to be some kind of probability distribution which doesn't *necessarily* say anything about the ontological constitution

classical mechanics. Entanglement is suprising from the perspective of classical mechanics because classical dynamics do not allow systems to become so strongly correlated. If entanglement is genuinely present at scales which are very well described by classical mechanics, it would be proportional to the degree that there are phenomena present *extraneous* to the description afforded by classical mechanics. So, even if we hold like Barad that entanglement is ontological, the amount of literal entanglement that could feasibly exist at this scale is itty bitty. Not to mention, even, that it is a difficult property to maintain in a quantum system, nor is it not a ubiquitous one. Not all interactions which change the state of quantum systems, for instance, create literal entanglement between the system and the apparatus that acted on it (Nielsen and Chuang, 2010).[3]

Entanglement also needn't be present for deeply entwined causal structures to exist. It can only be measured when we can accurately represent the state of a quantum system in a certain way—when it can be expressed as a distribution over a basis of an operator, like position. This mode of representing matter captures certain information about it: usually its position, momentum, or energy. If the system is entangled in one basis, it is entangled in every basis. But not all information can be represented in the framework of operators and bases. Is gender really able to be captured in this way? The history of a piece of metal?

of the matter in question. Saying that entanglement is 'just' a measure of correlation is, at a minimum, agnostic about the ontological quality of the quantum state. There may be evidence that can be found to say for certain whether the state is epistemic or ontic: see, for instance, Harrigan and Spekkens (2010).

[3]There are other interesting questions here about the role that hot and many-bodied environments play in the preservation (or lack thereof) of entanglement. It is well known that for quantum systems, a thermal environment will cause a pure state to become mixed, degrading any entanglement within the state. To what degree does the quantum state then become entangled with its environment? Some, as far as I can tell. But we do not live in a world where most of our atoms are in pure entangled states. For the most part, our atoms are part of complex ensembles with information that is far better described by statistical mechanics than by a theory which deals in quantum information. There is also a real sense in which thermalization is how information gets erased. In a warm, macroscopic world, thermal fluctuations are constantly erasing information by returning distributions to uniform thermal ones. I cannot think of a sense in which any possibly extant entanglement in these scenarios is relevant or *does* anything.

If it can be, I don't see how. Nor do I see how seeking a direct application of quantum mechanics to world history could be useful. The world already cannot be described by classical mechanics. Clearly, if entanglement is not strong at the scale of world history, then it is *not necessary* for complex entwined causal structures or to justify a relational non-individualist ontology.

### Theories are a Swiss Army knife

There being one real world doesn't mean that there is one theory which captures all of it in a useful way.

Barad works in the frame of quantum mechanics. Why not talk about quantum field theory (QFT)? There is a sense, after all, in which the world is *not* quantum mechanical, but quantum field theoretic. Quantum mechanics does not include spacetime, QFT does, and we know that spacetime is important. QFT provides fantastically accurate experimental results—probably providing several of the results that Barad references without citation when they argue that quantum physics supersedes Newtonian physics (p. 110). Extending Barad's argument about quantum mechanics superseding classical mechanics, QFT is clearly more true than QM. So what gives? What of how difficult entanglement is to define in QFT?[4] I will use QFT here to argue that treating any quantum theory like a universal theory is misguided.

Is QFT really a theory which supersedes quantum mechanics? Does it even supersede classical physics? I would say no. Laura Ruetsche, a philosopher of QFT, might agree with me. She takes seriously the idea that there is one world, but isn't convinced that we need

[4]Many researchers currently rely on quantum mechanical systems interacting with quantum fields to measure entanglement in them (Sachs et al., 2017).

one theory and one metaphysics to describe it. She's a self-described *locavore*. This is in opposition to an approach that would take a single scientifically-informed metaphysics. Rather, "the locavore contends that 'the metaphysics' of modern science, the framing commitments that promote legitimate scientific aims in all their guises, are multiple—and *that this multiplicity is a good thing*" (Ruetsche, 2014, p. 3426, emphasis original).

It turns out there are infinite non-equivalent ways to mathematically represent a QFT. These different representations are useful for explaining different physical phenomena—different physical phenomena which happen in the one real world, yet which are not able to be described by a single mathematical structure. So, there is no one consistent metaphysics of the world, at least not one informed by the most 'fundamental' theory we know.

In some ways, Ruetsche takes on a similar task to Barad in her book *Interpreting Quantum Theories* (Ruetsche, 2011). The book is about QFT and its interpretations, but she also identifies a specific goal of using a specific argument about physics to inform a general philosophical stance. Yet, she does not say that the ontology of QFT is literally maintained at all scales. Rather, the lesson is that we genuinely have many interpretations of the world from our many theories of it. They give interpretations which are often contradictory, but that's not a bad thing. Each bit of theory is like each tool in a Swiss Army knife. In this, Ruetsche demands attention be paid to scale and context and purpose. She is not interested in a theory of everything—even if such a thing existed, it would serve us better to address philosophical problems with our current theories and their successors than to wait around for ultimate success, or to philosophize about something that we do not have access to. We should be focused on what is useful as opposed to what is grand.

### Earth information exceeds quantum information

Taking land as our framework, it is clear that every object has a specific, emplaced history and future. Everything comes from somewhere. As I will argue below, this is important for how the objects of physics are part of land. Yet, we must be careful about equating different kinds of information.

A few paragraphs up, I noted that you can have complex causal structures, like that of political economy, without entanglement having anything to do with it. I want to elaborate on the differences between information at quantum and human scales.

Thermalization in quantum systems is instructive here. Say I have a little group of electrons in a particular state—say they all have the same vertical position. If I just leave them be, they will tend towards a state that is less special, where they are distributed randomly along the vertical axis. This is thermalization in an isolated system.[5] The first state can be thought of as having had some information. Its position distribution was unique, making it useful for representing a bit of information. You could assign "all electrons aligned low" as 0 and "all electrons aligned high" as 1. After the electrons spread out, the distribution is not very unique at all. There are so many ways for those electrons to be distributed, after all. In quantum systems like this, it quickly becomes difficult to tell the history of those electrons. Thermalization effectively erases that information at very short time scales. The quantum history of electrons quickly becomes irrelevant to their dynamics.[6]

[5] There are a few conditions to meet in order for this to happen, and those conditions are not entirely well-understood in quantum mechanics, but we do know that it is really very common. See e.g. Rigol and Srednicki (2012).

[6] It is a widespread, well-justified, and very useful approximation in quantum systems to say that the dynamics are Markovian. This means that the dynamics at each moment are only dependent on the state of the system at the previous moment—they are instantaneous and do not care about history. This isn't *always* true, so Barad might say that *strictly* speaking, no dynamics are Markovian and thus all histories matter. That would not be an argument I put much trust in.

Let's think about this group of electrons that I have. We can dispense with the usual physics mode of thinking about stuff as if it is the only thing that exists in the entire universe.[7] Instead, they are a real part of this earth. They're not isolated—most electrons are in atoms, after all. Maybe they are in a bit of copper wire. What is their history, on the scale of the earth? Copper is a conductor, so the electrons aren't tied to individual nuclei, but have the freedom to move around. Usually, they move quite slowly in random directions. If a DC current is applied to the wire, they move opposite to the current direction at a few millimetres per hour. So we can expect that for as long as the copper wire has been roughly that shape, most of its electrons have stayed with it. Before they were in that bit of copper wire, maybe they were in a larger chunk of copper. I'm not sure what happens to electrons during smelting processes. Maybe there is exchange of valence electrons between copper, oxygen, and silicon ions as they are separated from each other. Regardless, the electrons were probably in a bit of copper ore that was transported long distances using a massive amount of fossil fuels. Maybe that ore was extracted from the ground in the Atacama desert, where several of the largest copper mines in the world are.

The bit of copper wire has this earth-scale history in it, somehow. For Haraway, the history in objects is a tangle of threads, a ball of yarn: "you can explode them, you can untangle them, you can somehow loosen them up... they lead to whole worlds" (Haraway, 2004a, p. 338). Haraway says that "subjects and objects are sedimented" into something like a computer chip (p. 338, *ibid.*). Barad speaks of the liveliness of matter, the way that it has agency in its own intra-actions where meaning is inscribed.

Are these two stances compatible? If we are careful about scale, I think yes.[8] The

[7] Which is, seriously, a useful and common way to think about stuff, especially in QFT.

[8] I am not sure that Barad would ever think that these stances are opposed. I find their discussion of scale nevertheless in need of some clarity on the issue.

dynamics of the electrons as we attend to them within the wire don't care much about the geological history of wire, let alone their own position five minutes ago. Yet there are non-quantum mechanical causal influences across scales. For me to be able to manipulate the electrons at all, the copper wire coming from a particular mine through extractivist economic practices has to be in my lab, with all of its sophisticated technology and funding and lab techs and its university. This is a real and tangled way of earth-scale dynamics affecting quantum ones. And they influence earth-scale stuff back: a signal from my measurement of their position boots some other electrons in my computer into gear to record they way the apparatus was affected by their dynamics.

Yet the electrons will forget. Five minutes later, from the lens of quantum information, it is as if I have never manipulated them at all. The copper in the lab, though it may, like its electrons, have no information at a quantum scale about where it came from, cannot be without its history. Like the mark left on the computer that records the dynamics of the electrons, there are marks on the earth that have recorded its being excised of copper ore.

This is where I can see the Baradian approach tying the whole issue up by saying that there is entanglement across scales. But, at risk of belabouring my point, I think this has problems. The language of entanglement prioritizes the scale of quantum dynamics. The ontology of physics—classical and quantum both—has been prioritized for far too long. It is too easily universalized. Since quantum dynamics have genuine differences from earth-scale dynamics, this universality based on quantum ontology doesn't hold enough room for the durability of land as objects. Barad writes about us being a part of the universe. We are more a part of the earth. A single ontology elides the existence of land.

### Preserving the political position of physics

Barad is offering an ontology that is alternative to the one presented by classical physics. They contrast, for instance, "that while classical physics is premised on an inherent distinction between subject and object..., quantum physics relies on agentially enacted cuts" (p. 436). This assumes importance of the ontology of any physics at all to the social world.

We do not need to exclusively rely on the ontology of physics, whether classical or quantum, to tell us about the important scales and responsibilities and sustainability of the way we operate in structures of life. It is an unnecessary reification of physics to think otherwise. This is a trend in theorists similar to Barad: Sundberg draws on Watson and Huntington to say that posthumanist theories like Barad's "tend to 'glorify "modern" science and technology,' thereby privileging 'only certain human-nonhuman assemblages."' (Watson and Huntington, 2008; Sundberg, 2013).

Hollin et al. (2017) hold that Barad does not intend to draw on the authority of physics. Intended or not, they do. Surely, part of the reason their work has been so widely taken up is the socio-epistemic authority and mystical draw of quantum mechanics.

Barad is very familiar with quantum sciences and the possible responses from other quantum scientists to the claim that quantum mechanics applies non-metaphorically to the world. They are familiar with the ways that another quantum scientist might push back on their non-metaphorical method. Many social scientists are not. Overt attendance to quantum mechanics continues to award epistemic prestige to the study of physics, even in ways that spill over into fields like anthropology (e.g. Kirby, 2011). The use of quantum mechanics is not necessary to believe that some meaning is created during intra-actions. I will elaborate below on how we might upend this by positioning the objects of study of physics as part of land rather than positioning everything as quantum mechanical.

Barad's work has used the epistemic authority of physics & the assertion that its ontology is fundamental to become widespread. This is a problem. The belief that the work is fundamental is a justification for many physicists, even as they work for war agencies. The way I have tried to attend to scale here challenges this belief: studying physics tells us more about specific parts of the universe. And we are not merely in the universe. We are unavoidably on planet earth. It can't be that learning about the tiniest and biggest bits of the universe are always good for life on earth.[9] There must be more room to challenge the ubiquity and necessity of studying physics.

### 5.2.2 Matter matters and so does land

*Meeting the Universe Halfway* is one of the most popular texts of new materialism and post-humanism, a turn to deep ontology. Zoe Todd, Vanessa Watts, and Juanita Sundberg, among others, critique this movement for its euro-centrism (Todd, 2016; Watts, 2013; Sundberg, 2013). We're trying here to get at a way to understand phenomena of physics that will assist in anti-colonialism, so that's no good. I'll share some of these critiques here so that we can use Barad's phenomenon appropriately.

New materialism uses many ideas from various Indigenous philosophies without citation. Todd (2016) discusses the Inuit *sila*, which is climate and life, as an important concept to recognize and engage with when discussing climate change and the arctic. Latour came

[9] I wonder, for instance, about how Barad's framing of the importance of quantum physics has influenced the way people think about quantum computers. It seems pretty easy to go from 'quantum physics tells us something fundamental and useful about all scales of the world' to 'quantum computers must be useful'. Yet quantum computers are mostly useless, and if they benefit anyone, it is those with quite enough power and food on the table already (McKay, 2019a,b). Maybe this is an uncharitable read, since again and again Barad implores us to attend to specifics. But they don't attend to the specifics of quantum physics sometimes being unworthy of pursuing.

close to discussing something like it in a 2013 talk, but never named it. Barad mostly engages with scholars like Foucault, Butler, and Bohr. Clearly there is an absence of engagement of the scholars of new materialism with Indigenous scholars.

Barad does a lot of work to remove hard boundaries between objects; they go as far as saying that there are only intra-actions, not interactions. This is in response to an aspect of the culture Barad studies and works in—a euro-colonial culture. Barad "refers to a foundational ontological split between nature and culture *as if it is universal*" (Sundberg, 2013, p. 35). This is not present in all nations.

There is also, in Barad's work, an absence of attendance to the specificity of place and how it is wrapped up in specific epistemologies (Watts, 2013). They offer *one* ethico-onto-epistemology, falling into the settler conceit of needing or being able to provide one framework that will work for all people in all their different contexts. I noted above that Barad tends towards locating their work within the universe, rather than on earth. Relying on something positioned as universal—quantum mechanics—to inform the most fundamental ontological unit leaves room for a bit of settler epistemology of place (Seawright, 2014). In that colonial epistemology, no place is really deeply different from any other. They can all be boiled down to a fundamental ontology of stuff-to-be-manipulated, rather than an always-historied, always-in-more-than-human-relation complex setup of networked bodies. Watts calls this Indigenous Place-Thought, "the non-distinctive space where place and thought were never separated because they never could or can be separated" (Watts, 2013, p. 21). Barad pushes for complex networks and for the agency of matter—but what of the agency of each networked nation in the structures of land to operate on its own scales? What of the acknowledgement of the harm that physics has had on specific lands, like the nuclear tests on stolen Western Shoshone land (Broze, 2019; Solnit, 2014)? How does propping up physics as that which defines ontology allow room for physics to be accountable to the harm it has done to particular lands? What room is there for responsibility to the legal practices of Indigenous nations who have been under occupation for centuries? In order to understand phenomena in an anti-colonial way, there must be an understanding of physics as tied to land as tied to law.

Finally, attending to physics or matter generally as opposed to land and particular land epistemologies creates errors in how we think about time. Barad certainly wants to mess with the most typical linear conception of time by creating room for past and future to be part of the enfolding of the present, and to be affected by the present. But why should time be defined by quantum phenomena? Or defined in some opposition to time in classical physics? Is there room for time to be defined by ecological, geological, and social scales? Sheridan and Longboat (2006) discuss time in a Haudenosaunee worldview: "To know deep time is also to understand sky, earth, water, and spirit in their sacred interaction, and to know this attains an equivalent depth of human belonging to deep times continuity in the present" (p. 372). Clearly, time is about more than subatomic particles. We can see, again, that earth information is different from quantum information. The deepness of time is also infused with an ethical imperative to be responsible to seven generations in the future: time is inseparable from law. They talk about "round time" at various scales (p. 372). There is an impetus within ecologies to return to "sacred time's *forever*" (p. 368, emphasis original). This is a recognition of the agency of complex networks of life to seek balance, like the return of blueberries in Sudbury after emissions from the nickel smelters were reduced in the 70s. The size of the circle of time depends on the process. Blueberries return quickly. Rocks don't.

## 5.3 Seeing with earth-made eyes

Barad talks at length in *Meeting the Universe Halfway* about physics experiments in order to demonstrate their concepts of apparatuses and phenomena. They extend the traditional boundaries of experimental apparatuses to include people, nationalities, and tobacco habits. To demonstrate my modification of their sense of apparatus, I will extend their example of the Stern-Gerlach experiment.

The Stern-Gerlach experiment is a classic of quantum physics (and the bane of many second-year physics students). In Quantum Physics I classrooms across universities, the Stern-Gerlach apparatus is depicted in a simple, diagrammatic form, often on a webpage where one can click a few buttons to shoot particles through a magnetic field and measure their spin via their path deflection (see figure 5.1).

Let's review the experiment briefly. A bit of silver is heated in an oven. Silver atoms are ejected from the oven and focused through an inhomogeneous magnetic field. They land on a screen, with their positions indicating how they were deflected when they passed through the magnetic field.

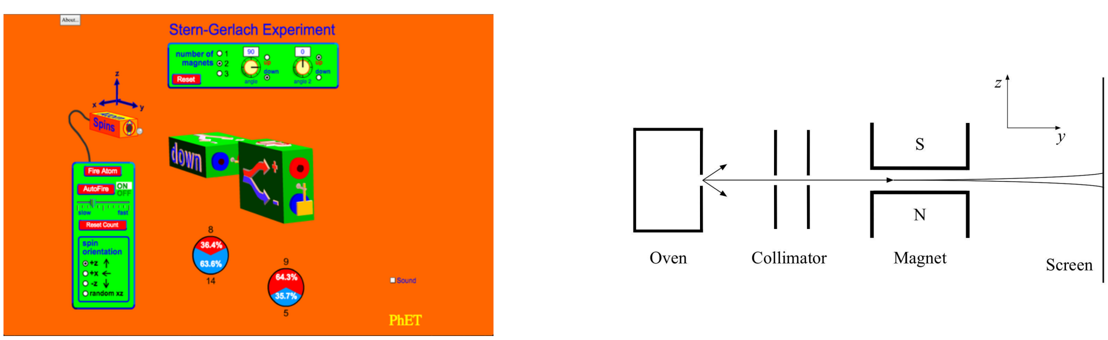


Figure 5.1: Left: a colourful PhET simulation of the Stern-Gerlach experiment, where one can press buttons to measure spin direction (PhET, 2020). Right: a simple line drawing of an experimental schematic (Steemit, 2018).

The typical depiction of the apparatus in a physics textbook includes essentially only this. There is little mention of what Stern and Gerlach were aiming for or how they got there. It is made to seem like a simple fact of nature just waiting for the boys to set up a couple of silver atoms and magnets to become clear.

Barad changes this narrative. First, they emphasize that neither Stern nor Gerlach knew that they were measuring spin to begin with (Barad, 2007, p. 166). They sought to provide evidence for spatial quantization. This emphasizes the liveliness of matter; it's surprising, sometimes. It also wasn't as definitive as normally portrayed. Initial results did not indicate clear beam splitting: "Although virtually every quantum physics textbook hails the Stern-Gerlach experiment as a definitive and straightforward result (push a button and note what happens), it was only years afterward that the results were given their current interpretation" (2007, p. 166).

Second, and more importantly for my argument, Stern and Gerlach were able to read the screens that the silver atoms landed on because of cheap cigar smoke, the sulfur in which turned traces of hard-to-see silver into noticeable black silver sulfide (p. 165). Stern watched the traces of particles appear as he breathed sulfuric breath onto them. Barad redraws the apparatus, reproduced here in figure 5.2. This is used to illustrate what they mean by an apparatus:

> Apparatuses are not static laboratory setups but a dynamic set of open-ended practices... [A] cigar is among the significant materials that are relevant to the operation and success of the experiment... Not any cigar will do. Indeed the cigar is a "condensation"—a "nodal point," as it were—of the workings of other apparatuses, including class, nationalism, economics, and gender... (p. 167)

They do not mean that the silver atoms were pushed to one side *because* of the cigar, or that that was the only way to see the result. Rather, "the social and the scientific are co-constituted. They are made together—but neither is just made up" (p. 168).

Fine. This sounds great so far. The boundaries of apparatuses are not hard, though they are often represented as so in physics literature. The phenomenon of silver atoms being split by their electron spin direction, in the instance of the Stern-Gerlach experiment, included cigar smoke and everything that brought the cigar smoke to touch the silver atoms.

Still, the Stern-Gerlach diagram with a cigar does not include an acknowledgement that the magnets or the screen or the silver atoms came from somewhere before they were constructed into this apparatus, the original physical version of which is shown in figure 5.3. The origins of the materials are not included in the representation of the apparatus—another way that practices of physics continue disoriginining.

On what basis can we include them, anyway? Barad includes the cigar smoke because it had a causal effect. It turned silver into silver sulfide. It made the path of the silver particles

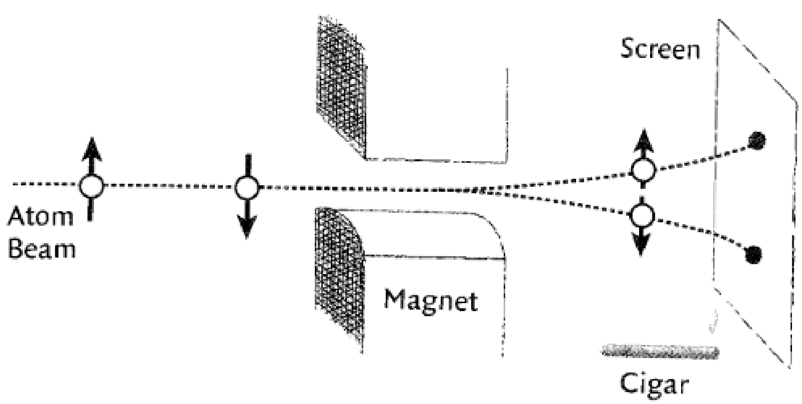


Figure 5.2: The experiment performed by Stern and Gerlach in 1922 would not have worked in the way that it did without Stern only being able to afford cheap sulfuric cigars and being allowed to smoke them in the lab. The boundary of the experiment is expanded in this diagram. Illustration by Nicole Roger Fuller (Barad, 2007, p. 165).

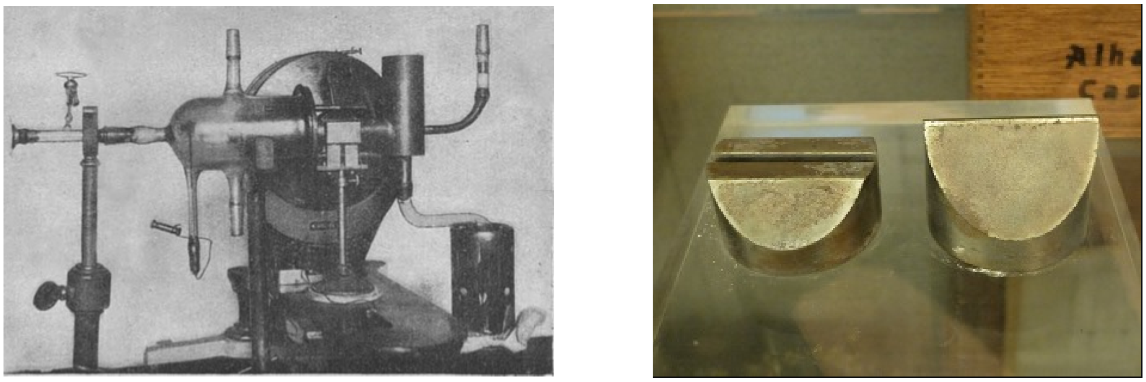

Figure 5.3: Left: The physical apparatus of the original Stern-Gerlach experiment. It appears that many more materials and fabrication techniques were used than those represented in the diagrams (Germach, 1925). Right: The magnets used in the Stern-Gerlach experiment, now housed at Carnegie Mellon University in Pittsburgh. Whose hands brought them to Frankfurt? What land did they once belong to? Photo by Pierre (2014).

traceable. What would it matter where the silver atoms came from before this? Smelting removed almost all atoms which were not silver. The smelter physically disorigined the metal, removing traces of its physical context in ore, in geology, in geography. It is highly unlikely that the physical content of a sample of silver would have had a noticeable effect here. I do not want to include the origin of a metal in the description of an experiment because I wrongly assume it effects 'the science' like the cigar smoke did.

I want to include the origin of metals for a stronger reason: their presence makes the experiment possible. Without the silver atoms being in Frankfurt in 1922, they would not have been on a path that could be measured. Without the magnet, likely made of iron, that path would not deflect. Without the screen, there would be no record of their deflection. It is not so much that this silver or that silver changes the experiment, but that the presence of silver at all creates the possibility for the experiment. The presence of silver in turn was created by hundreds of years of the practice of extraction *and* by the specific extraction of those specific silver atoms from the crust of our only planet by human beings. Without access to a bit of the material power created by extraction, Stern and Gerlach would not have been able to create the conditions where silver atoms and magnets and cigar smoke and screens acted together with the experimenters to produce something which could be read as the bi-directional nature of the magnetic moment of atoms. This is more than a platitude of gratitude for the sacrifices made for science. This is an assertion that the objects of study of physics exist only because of apparati made from the fruits of extraction. Physics enfolds into being together with these metals. We see with earth-made eyes.

*All* of the phenomena of physics happen in apparatuses that come from the ground. That doesn't necessarily mean that they wouldn't exist if not for extractivism, but it is honestly hard to imagine a world where technology exists that requires dozens of metals mined from all over the world *and* where the relations of land are truly respected and maintained with the intent to maintain them for thousands of years.

I do mean all phenomena. Theory is not an exception, here. That work often depends on computers, first of all. Second of all, the work is deeply tied with experiment, with experiments prompting theory and vice-versa. Most physics work is expected to be testable; a theoretical claim ought to be able to be fit into the physical framework of a lab or a telescope and corroborated or dismissed.[10] More than that, any one physicist's work depends on the past hundred and fifty years or so of experimental and theoretical work.

It is not that there are no parts of the world which exist without human interaction. The bits of matter that we call electrons seem, by every reasonable estimation, to exist everywhere and without our help. But, in keeping with Cartwright (1999), the only time that a group of silver atoms are divided into two by the direction of their electron spin is in a lab doing this experiment.[11] The only time it becomes legible, controllable, and neatly

[10]Though significant exceptions have been made to this, as with string theory (Prescod-Weinstein, 2020).
[11]Cartwright does in fact go further in suggesting that physics is created entirely within the lab and that

describable as an object of study of the practice of physics is by the particular arrangement of objects in a lab, built on decades of published and tacit knowledge of physics workers. Otherwise, as discussed above, it has relations with other parts of the world, and histories unknown to humans, and an existence unto itself (Scott, 2019). It's just that, in those contexts, it doesn't belong to the human practice of physics.

I'm not making this argument because I want to make the practice of physics more accurate or efficient—I don't care about that, actually. I don't think that attending to where the silver in an experiment comes from will likely change the answer to questions about quantum behaviour. I *do* think this argument can change what research questions are asked. If we do not ask in a particular lab how to make indium-gallium-arsenide into a single-photon source, then there will be no instance of single-photon behaviour in that lab—an instance of human dynamics causally affecting quantum dynamics, across scales.

If we consider the actual stuff of physics to be landed, we can no longer pretend that physicists study stuff that is, on some level, unrelated to the rest of the world. Physics is *not* the study of the universe. It is the reading of bits of the universe created strictly within the bounds of—and with the tools, the eyes of—the earth.

## 5.4 Conclusions

The objects of study of physics are particular. They are the interactions of humans, lab computers, thin films, lenses, and so on. They happen on land with particular history. They are made of land that comes from many places. Their behaviour does not give us a unique ontology to apply universally. Their behaviour does not set them uniquely apart

we should take seriously the idea that the laws of physics routinely change.

from land-based law.

The study of which laws apply to extracted materials that become a part of physics phenomena is outside the scope of the thesis and my expertise. There is, at minimum, a precedent in the Dish With One Spoon to attend to keeping the land clean—something we know that mining does not do. In the next and final chapter, I will explore more options for how physics can resist extractivism and colonialism.

# Chapter 6

# Moving towards a landed physics

The dominant way that physics is perceived and done in eurocolonial society is consistent with extractive logic, from writing practices to phenomena. Not only are experiments built with extracted materials, but they are often built to further the production of consumer or military technology, increasing demand for extraction. In answer to my first research question, I showed in Chapter 3 that the scientific writing of physicists is a part of extractive structures. The articles I analysed there show research motivated by technological applications and funded by war organizations. The authors did not attend to where their materials came from or where they would go to once they were finished with them.

In trying to undo the disorigining that allows physics workers to act as though their work is disconnected from the earth, I told a land story of indium in Chapter 4. This responded to the first part of my second research question: how are the practices of physics a part of land? Colonial efforts opened up a mountain in southern Bolivia 475 years ago at the expense of people and forest. A smelter in western colonial Canada that processes indium on occupied territory launches lead dust into the air. Discarded screens sit in piles of e-waste leaching chemicals into water. Using the framework of land introduced in Chapter 2, we can understand that every bit of land in this story is connected to the other ones, and that connections imply responsibility.

Finally, in Chapter 5, I provided an ontological argument to understand the entirety of physics as a part of land. This responded to the second part of my second research question: how are the phenomena of physics a part of land? Though a quantum field may exist everywhere, we are only able to come to know one by using bits of the earth arranged by us to make it act in a particular way. Thus even the phenomena of physics that sometimes seem so far from earth or the complexities of life are really a part of land, though they are produced in extractive structures.

In light of us all being a part of land and having responsibility to those we are in relationship with, it makes sense to ask where to go from here. Many practices in physics are part of extractive systems. How could it be different? Part of an anti-colonial effort? How can physics workers be responsible in their work to their relationships with all the parts of land? A common response to the ethical problems of extraction is to try to use 'fair trade' and 'conflict metal' policies, to get rid of the 'bad metals'. In section 6.2, I'll argue that neither of these policies are sufficient, and that we must oppose the structures of extraction at their root. Then, I will make non-exhaustive suggestions for action that physics workers can take in section 6.3. The discussion of tactics for change in an essay targeted at scientists provides some answer to my final research question: how can STS work be usefully targeted towards science workers?

The issues I raise here are not intended to be about speculation for a more effective physics. Few of my suggested paths for action would result in much more physics work getting done. I am using the term 'landed physics' to indicate something to move toward, but I'm not really even convinced by that term myself. If we took land seriously, would science really be so divided from the rest of knowledge? Would physics exist in a recognizable form? I suspect not. I will argue why we should seek to let go of physics in section 6.4.

Before I delve into practical tactics, I will spend some time with the overwhelming nature of the situation. In processing something as enormous as extractivism, it's sensible to attend to emotions before trying to move into action.

## 6.1 Being overwhelmed in a messed-up world

The world is fucked. There are plenty of good things, like birds and chatting and plants, but there's just such an awful lot of very old very entrenched very bad shit. Sometimes I feel overwhelmed. Sometimes I worry that since everything is connected to something exploitative, I can't do anything at all. In Chapter 5, I argued that the entire practice of physics, from theory to experiment to weapons applications, was built on extraction. What is a physicist to do, then? In Chapter 4, I talked about how workers and their land in Bolivia have been exploited for hundreds of years, and how this is a main reason that we have indium available for consumer technology at all. What is a person writing their thesis on a laptop with a screen lined with indium supposed to do?

I want to first acknowledge that there is a lot of grief to feel here. The destruction of life on our planet is and has always been grim. I touched on several genocides in this thesis. All of this destruction has been building for centuries now into a mass extinction. Grief about this and our spiralling climate is very difficult.[1] And it makes sense to feel it, to spend some time with it, in whatever way that one feels grief. When we know our own

[1] As I write this in mid-July, Toronto is experiencing its first rain in weeks. It is such an intense storm that I am a little scared. A small reminder of our intensifying weather. The future is terrifying.

grief for ourselves and for others, and have felt it through, we can move forward together with that grief to action.

So, carrying our grief with us, how do we confront the way we are tangled in webs of extraction? When some of us may feel like we cannot move for the possibility of pulling a string on yet more violence? Let's take direction from Liboiron et al. (2018a), who "take as [their] starting point a permanently polluted world" (p. 332). They draw on Shotwell (2016), who argues against the idea that the world used to be pure and beautiful. We can imagine what the world might have been like 'before' all of the problems introduced by humanity, but "the slate has never been clean, and we can't wipe off the surface to start fresh—there's no 'fresh' to start" (Shotwell, 2016, p. 4).

There is no way to live without hurting oneself and others. That's not what life has ever been, even 'before'. There is no world of overflowing abundance. The "real, possible world... offers finite freedom, adequate abundance, modest meaning, and limited happiness" (Shotwell, 2016, p. 5).

We cannot avoid toxicity. Simply separating out that which is bad is not only not possible, but does not confront the "social, military and other power structures that engender toxicity to begin with" (Liboiron et al., 2018a, p. 332). Seeking the impossible pure form of action will only leave us in stagnation. We genuinely need to act against these structures. It's not quite that we need to stay strictly within their self-defined bounds—that oft-discussed imperative to work within the system—but that we are tangled up in them anyway, inevitably. It's not like anything goes, but there will be hurt and inconvenience and a whole lot more along the way of tactically acting against colonialism and extractivism.

We could think of a tailings pond, maybe. It's big, it's in the ground, it's full of stuff that hurts people, maybe arsenic and lead and a whole lot else besides. A desire for purity might look like a desire to be rid of it. And an understandable desire that would be. But it can't go anywhere. And if it did go elsewhere, it would still be somewhere on this earth. Humans were the ones who made that tailings pond out of rock that used to not hurt anyone; probably a certain colonizing class of capitalists opened the mine and exploited the labour of poor working people to operate it. Humans of some kind are the only ones who can attend to the tailings pond. Humans can make sure its pumps are in working order. They can maintain the dam (for a while, anyway). They can make a warning system for when things get more immediately dangerous. And they can work so that more tailings ponds don't get built.

## 6.2 Is there an ethical way to buy a metal?

In some of the ethical systems I touched on in Chapter 3, there is a focus on personal choice to not participate in things that one finds unethical. In the context of mines, this might look like excluding 'bad' mines from a supply chain. There's quite a lot of attention paid, you may have noticed, to children mining cobalt in the Democratic Republic of the Congo, and to the use of some of the profits of those mines to fund local militias. Tin, tantalum, tungsten, and gold are labelled 'conflict minerals' for the same reason. If we just stop the bad parts, the logic goes, maybe it will be okay.

So we've done things like create labelling systems for conflict minerals deemed to be 'clean', in contrast to the arguments of Liboiron et al. (2018a) and Shotwell (2016). Radley and Vogel (2015) make a compelling argument that this labelling system has done little even to minimize the size of militias. Instead, it has made it more difficult for men to be employed at the mines. So, some of them actually seek employment with the militias. There are many problems with this program—it didn't attend to the needs of the workers, for instance, instead identifying the problem as somehow being with the metal. More deeply, it operates on a fundamental assumption that an ethical purchasing relationship can be achieved (and that it's rather straightforward to do so).[2]

Even if, somehow, American legislation played a role in building stability in a region,[3] and the workers had appropriate safety equipment, and the wastes were attended to as best as we know how, then would the tantalum be 'clean'? There would still be wastes, soils disturbed, plants torn up. There are thus no workers unaffected by mines—at least not workers who live near their mine sites. And there will always be a host of technologies made with materials extracted from other sites. The rock wouldn't grow back. Much of the technology for restoration after a pit is operational is superficial at best (Kuyek, 2011; Kneen, 1999). And, again, mines are not operated in this way. Corners are constantly cut. Artisanal workers do not have PPE. Slag gets tossed in rivers. There is no clean mine.

I want to emphasize that the problem here is not only capitalism. I have focused on extractivism and colonialism throughout the thesis, noting that capitalism rests on both of these structures. That was intentional: if we could put everything in the hands of 'the workers', it wouldn't necessarily fix the problems of extraction or colonialism. As Martín Arboleda (2020) writes, "the radical democratization of the forces of production is not enough" (p. 259). A democratically operated mine is still one which permanently extracts value at great cost to the ground itself and all the rest of the nations there. Emancipation would require us to overcome all of the rifts of alienation tha twe experience from labour,

[2]One can also be more deeply cynical (and probably accurate) about the program: nobody who designed it ever wanted to accomplish anything like stability in the region or fair working relationships with miners. The American congress has a deep interest in maintaining instability in many places in the world, and they've been very successful at doing so.

[3]Literally laughable.

objects, machines, and the ecological world. The land belongs to itself, not to the workers.

So, we cannot and should not imagine a clean mine. The indium in someone's lab will not be pure just because it didn't come from Bolivia.

Yet. I was just talking about how we ought to reject purity. Here, I mean at least two things by that. One: if we think purity is possible, we might put all of our efforts into making a clean mine. This is not possible. It is not a good idea to put all of our tactical eggs in that basket. It is not a good idea to think that we are absolved because we were able to purchase from a smelter with a less abysmal record than Teck's. We cannot seek the same structures, but clean. We must remove the structures. Two: some mines really are better than others, and that's got some kind of value. Mines where workers have power and protection from harm are better. Mines which provide adequate compensation and healthcare are better. Operations under a nationalized system are better than those under a corporate imperialist system. Tailings ponds with well-designed, well-maintained architecture are far better than those with dams that break (Friends of MiningWatch, 2019). Fighting against corporate imperialism and for workers' and environmental protections is genuinely worthwhile for all it does to lessen the violence experienced by people and their living surroundings.

There is something to balance between these two points. Reforms pose their own dangers. So-called socially responsible and sustainable mining has gained a serious foothold in the corporate lexicon and strategy handbooks. Mining conferences run long sessions on restoration and on consulting with local communities. That would be cool if it wasn't essentially a PR stunt. The existence of these programs puts another layer of defense between them and those who would critique their operations. It's easy for people who are underinformed and sympathetic to mining to point to the existence of these programs as evidence that mining isn't all that bad.

There are also ways that metals are used which are not about increasing military power or corporate profits or wonder, but used for life. We use iron to build apartments. We use steel to pipe water to our sinks. We need mobility devices, made of alloys light enough so as to actually be usable. There is a vast range of assistive and medical technology that is invaluable to millions of disabled and ill people worldwide, and thus is invaluable to all of humanity. That doesn't make those mines clean, or excuse even close to all technology. It just makes them more complicated.

We cannot buy our way out of this problem. And we can't make a simple demand that we just stop, whatever that would mean. Nonetheless, we can commit to opposing extractivism. We can, for instance, ask to drastically reduce the amount of many of the metals we mine—surely, nobody needs more gold.[4] We can make strategic decisions in support of thought-out tactics aimed at a particular node of extractivism, including ones we might find ourselves working in.

## 6.3 Ways to move forward

Physics workers can strategically act for more responsible relationships. Recommendations are often given exclusively to those who already have power—department chairs and journal editors. I have found that these types of recommendations are often ignored. My approach here is to provide notes on strategy for those without much power, like graduate students. I discuss starting points for goals and tactics broken down into categories of approach.

I will not make a recommendation that we establish Research Ethics Boards for physics, since the systems of ethics that they operate under do not generally oppose extraction.

[4] And if they do, they can take it from the Federal Reserve in New York, which holds at least a fifth of all the gold we have ever extracted from the earth's crust (Graeber, 2011, p. 363).

Further, I do not want to recommend a course of action that can be used to legitimize extraction.

There's a lot here; it's not intended to be an agenda for everyone's course of action. Some of these suggestions will not be feasible or even useful everywhere. Some cannot be taken until others are well on their way. Like all action taken to change society, there could be possibly serious consequences. Consider them. Act in solidarity with others, take security seriously, and be careful.

There are many themes in tactics. In order to negotiate with bosses (including PIs, department chairs, journal editors, and granting agencies), build labour power. Address emotional and financial precarity as a foundation for other work. Build new narratives through writing, workshops, and discussions. Use media, including tweets, blogs, opinions pieces, and journal articles. Participate in and organize protests. Join organizations resisting extraction, militarism, and racism. Be creative, though—remember the people opposing these tactics are well-resourced and have been fighting for a long time.

Strategizing effectively can take a long time and is not always 'successful' in the usual sense of the word. Sometimes the result is improved relationships. Sometimes the result is ambiguous. Always, the process and results are particular to the place and the people and the actions under contestation.

Now, there are many paths for action! Much work in equity, diversity, and labour organizing is useful for building power of physics workers in their workplaces, which can then be used for the following paths. Physicists can agitate for Indigenous law and treaty relations to be followed. Physics papers can be written more slowly, taking as valuable more of the context of the work. Communities resisting mining are in need of solidarity. Some projects are not needed—if workers have more power, they can practice refusal in the tradition of Luddism. There's plenty of military funding and rhetoric in physics—there's lots of narrative-building to do there in resistance. In place of these unsavory parts of physics, more focus can be put on community-driven problem-oriented research, maintenance of our current knowledge, and education.

## Building power within physics

Physics is known to many of its workers as being highly competitive and full of racial and sexual harassment. A kinder field that attends to the humanity of its workers far before it demands their productivity would have a lot more room for criticism of the field, research into land, and responsible actions. Success here can form the foundation for successful actions on other axes.

**Goals** Build time and emotional space for workers to slow down and take on non-physics tasks. Build negotiating and labour power.

**Tactics** Unions can be powerful. Unionize grad students, adjuncts, lab technicians, and faculty. Though far from a trivial endeavour, the negotiating power gained through unionizing is huge. Campaign for living wages, health benefits, and worker protections. Imagine what cross-university unionizing might look like.

Harassment is rampant in physics. Responses at multiple scales are needed. Implement codes of conduct in research groups, clubs, and conferences (e.g. FemPhys, 2016; Barrio RQI, 2017). Get training from community mediation organizations for responding to harassment (e.g. St. Stephen's Community House, 2020). Read about transformative and restorative justice and use them to inform response frameworks that can be implemented by small groups (e.g. Dixon and Piepzna-Samarsinha, 2020). For instance, firm boundaries can be established between harassers and those who have been harassed with the help of support persons. Media campaigns can be mounted against serial harassers who are not facing consequences at universities (Oulette, 2015). Diminish the power of professors over students with tools like unions.

Community spaces can foster supportive relationships and alternative analysis of physics work (e.g. Ong et al., 2018). Power is built in friendship and solidarity. Build these spaces with the people they are meant to be for. Use solid accessibility practices (incl. Leary, 2020; Belfast Trans Resource Centre, nd). Run social events of varying degrees of formality, academic help, and discussions which connect participants to thought outside of physics.

Relationships can break when people are forced to work a lot and move frequently. As a reach goal or a tactic for people in power, hire local grad students as postdocs and local postdocs as faculty. Campaign against the precarity of adjunct faculty, while advocating for the creation of permanent, unionized part-time positions. Design programs with fewer courses—focus less on producing 'excellent physicists' and more on maintaining the well-being and ethical power of individuals. Do narrative work against the idea of excellence. Focus on doing good, not being great.

## Treaty Relations & Decolonization

Every physics department in Canada is on Indigenous land. I have presented in this thesis an argument that the work of physics should attend to Indigenous law. These tactics ought to involve the leadership of local nations and Indigenous students.

**Goals** Follow Indigenous law. Give land back. Dismantle the colonial state.

**Tactics** Universities have now expressed interest in Indigenization. Use this interest as a tool in media, departmental meetings, etc. for making demands. Demand the university give land back and follow Indigenous law. Recognize that many treaties were made coercively; investigate the law of local nations.

Work with Indigenous lawmakers and physicists to explore how local labs could follow local laws. Include Indigenous science, physics, and astronomy in the department, recognizing that this will expand the scope of the department into land. Join protests and agitation in support of land defenders and missing and murdered Indigenous women, girls, and two-spirit people.

## Writing & publishing

I have argued that physics writing is one place where disorigining is continued. It is also a location of overwork for physicists.

**Goals** Discuss land and labour in publications. Publish slowly.

**Tactics** Physics workers can change the genre of physics writing. Include land stories or tidbits of information about materials used in experiment in papers. Write about choices made or possible difficulties in finding low-impact materials. Acknowledge the work of lab techs and grad students; point out labour inequities. Use grammar that acknowledges personal agency in experimentation, highlighting the fact that physics is done by humans in conjunction with materials.

Journals will often refuse to publish material which they do not believe to be directly relevant to the experiment. The ubiquity of publishing on the arXiv, an online pre-print repository, is useful here. Publish on the arXiv and cite arXiv versions of papers where allowable. Use arXiv overlay journals and encourage these smaller journals to broaden their editorial scope.

The rate of publishing required to be 'successful' is too high. Slowing this rate and reducing total publications required to have a career will be helpful for labour power and equity. Hiring & tenure committees should consider candidates with fewer publications. Thinking big, coalitions of faculty unions could throw weight into this struggle by refusing to publish. On a smaller scale, those who are already successful can refuse more authorships (and awards, for that matter). Reducing the number of publications that successful professors put out could eventually reduce expectations of hiring committees.

## Solidarity with communities in resistance

Many communities close to mines and other extractive projects have been resisting them for a long time. Their campaigns vary in strategy and size. Many are Indigenous nations defending their own land. Many are under threat of violence. Dozens of land defenders are murdered every year, all over the world (Global Witness, 2019).

**Goals** Support communities resisting extraction.

**Tactics** Acting in solidarity with each of these communities and their campaigns will look different. Join local activist networks who connect with communities and take direction from them. In Toronto, the Mining Injustice Solidarity Network is a good place to start. Learn about communities, the tactics they use, and the goals they have.

Join and support protests. Bring your research group. Lots of coordination, advertising, and day-of volunteering is necessary for a good protest. Join the organizing group, make signs, marshal, run media—there are lots of ways to help.

Communities in legal battles are often in need of expert witnesses. Fluid dynamics, geophysics, and engineering expertise could be useful.

Physicists have some clout. Use this in the media to help spread the message of communities, especially if you have a connection through your work to the material that comes from the extractive site in question.

## Luddism & refusal

Technology is not always good. The Luddites knew this. An organized group of textile workers in 18th century England, they smashed mechanized looms installed by their bosses when they threatened worker power (Hobsbawm, 1964). Neo-Luddite movements are against technology that concentrates power and uses resources unnecessarily (Lachney and Dotson, 2018). They are not afraid to consider a world with fewer machines.

**Goals** Change the view that technology is inherently good. Destroy or do not make technology that we do not need.

**Tactics** Begin with methodological Luddism—imagining the world or physics without certain technologies (Luís Garcia et al., 2018). Write about these possibilities so that others may also imagine it. Write about the risks of technology in physics papers. Do not write glowingly about unnecessary technology.

Pick projects which are lower resource, relying on extant tech or already-collected data.[5]

[5] Though we must remember that collected data is not a free resource, either, since it takes energy and computers made of silicon and metal to store it.

Pick projects which are unlikely to be useful. This may require misrepresentation of the project in grant proposals (but that's not abnormal anyway). Refuse participation in high-resource projects.

Build labour power with an intent to foster the ability to refuse work.

## Anti-imperialism & anti-militarism

Physics work has and often still does support military work. There is a history of resistance within physics, which reached a peak during the Cold War (Moore, 2008). Organized anti-military sentiment is harder to come by these days, likely because of concerted efforts to destroy anti-war movements through COINTELPRO and propaganda (Anderson and Mirrlees, 2014; Saito, 2002). This direction is difficult but has the potential to be powerful. As everywhere, work with others as much as possible, and be careful.

**Goals** Do not further imperialism and militarism in physics. Obstruct imperialism and militarism through physics.

**Tactics** Every physics worker has connections of some kind with militarism. Analyse these connections. Publicize the analysis to shift the narrative of science as netural. Research military projects in or near your area of expertise and share with anti-war organizations, especially if the project is not well-known.

Assist anti-war organizations in day-to-day operations. Participate in abolitionist movements against cops, prisons, and militaries. Act in solidarity with victims of war.

Protest the platforming of weapons manufacturers at physics institutions or career fairs. Keep in mind that these companies work hard to make their weapons work seem innocuous.

Vocally refuse military funding and collaborations between science funding and war organizations, like NSERC and the Department of National Defense.

Diversity efforts are funded in part because science and tech expertise is necessary for America and Canada to maintain imperial power (Paarlberg, 2004; Ong, 2005). We cannot resist this merely by saying that it is a bad motivation for diversity. Resist this motivation by actively obstructing the utility of science for militarism.

Thinking big, obstruct work at military labs and private industry. Aim to collaborate with relevant unions if possible. Support workers in the arms trade, not the arms trade.[6]

## Community-driven problem-oriented research

Physics tends to not address problems that are immediately relevant to communities. In "(Baby) steps towards feminist physics," (2012), Barbara Whitten talks about the potential for physicists to do community-driven research that genuinely addresses a problem.

**Goals** Run physics research on a problem-by-problem basis for & with communities.

**Tactics** Learn about participatory research in the sciences (e.g. Liboiron et al., 2018b). Connect with communities. Do not assume there are problems. This will take a lot of work to build useful toolkits for people-relevant science.

## Maintenance & education

When we refuse research projects and slim down our dependence on using and producing high-resource and likely militarized technology, a likely outcome is a reduction in things to

[6] In Canada, see Labour Against the Arms Trade.

do. Refusing to do some science means a slower science, to be sure. Yet there is already so much knowledge kicking around.

**Goals** Shift the focus of physics to maintaining knowledge rather than expanding it.

**Tactics** Develop skills in librarianship, archiving, and education. Build the narrative of maintenance as important. Shift current focus on physics education from education in support of the current structure of physics to education for maintenance of knowledge.

## Limitations to these strategies

Many junior faculty are already struggling as adjuncts. Unions are non-existent or failing. Some of the goals above are genuinely out of reach while we are facing the crushing boot of neoliberal economics and living with the results of decades of well-resourced state suppression of resistance. Those who are interested in change are few and stretched thin. There are dozens of possible projects for changing physics which each would require enormous amounts of work. Often the people interested in change are marginalized and subject to harassment. Backlash can be very real. Refusal can mean that those who are interested in individually amassing power have more opportunities for it. The people with power to change things within departments generally just don't. And every physicist is subject at some level to the decisions made by those who distribute grants. This is what it is to work within a system that operates on massive power discrepancies.

Being conscious of limitations and risks is very important. It doesn't mean that we cannot do anything, though. That's part of the reason why I have tried to engage with so many areas for action. If one area is limited, another might not be. Or that limitation may tell you about how power works and point to another of its weaknesses. It can be helpful also to consider what a limitation is for each person and why—this can tell us about power and help us to reflect on what is important to us.

## 6.4 Loosening our grip on physics

I spoke in the introduction about what I meant when I talked about 'physics'. In many ways, I mean something based on my own experiences as a student and researcher, as anyone does. I loosely defined the scope of the research as applying to institutionally practiced and historically eurocolonial physics.

This starting definition and the ensuing discussion did some boundary work. Through my investigation of my first research question, I asserted that writing practices in experimental physics disorigin materials and that lab practices benefit from extractive structures. I could be missing lab practices which are highly connected to land. If those lab practices exist, I have written this thesis as if they are not a part of the physics I am talking about.

There are many practices outside of this narrow definition of physics which are highly connected to land and which resist extraction. In the previous section, I suggested some ways that physics workers could take on some of those practices as a part of their work. If those actions were widely taken up, would it fuzz the edges of what counts as physics? If writing land stories were a part of physics, surely skills in history, ecology, political economy, and deep listening would be as well.

But I don't want to redefine physics. I'm not committed to the idea of a 'landed physics'. I don't really want to assert that solidarity work can be a part of it—if Luddism and land ethics were taken seriously, the whole discipline would be drastically different.

To genuinely change the practice of physics, we have to let go of there needing to be a physics at all. Its current structures of education, research, publishing, military & government funding, venture capitalism, and demarcation from other fields do not serve responsible relations. We must let go of these structures and build something new in their place, unattached from the goals of what physics has been up till now.

We do not need a physics that seeks to build a quantum computer. We do not need a physics that *must* know exoplanets. We do not need axions. We do not need particles. What we need is a planet on which life thrives. There is no doubt that the practice of seeking knowledge can be kind and just. Neither exoplanets nor electrons are responsible for the unjust ways that they become legible to us. It's not that nothing good comes from our current search for knowledge—these things are beautiful. It is an honour to know them. But I know also that it is an honour to know the rich, complex, stinky world of forest floor and bird flights and carrion, or to work for food for your community, or to spend time fighting for our world. It is the deepest honour and the wealthiest thing to be a part of a world with good relations that you know will last.

As it currently stands, practices within physics generally support extractivism. Extractivism, along with militarism, colonialism, and capitalism, is hanging the world out to dry. The climate catastrophe is upon us. The discipline is not exclusively responsible for everything bad that it is involved in, yet everyone involved must act responsibly. The world doesn't need the physics that currently exists. It needs physics workers who resist, for everyone's sake.

# Afterword

If you found this work useful and you are seeking to oppose colonialism, militarism, extractivism, capitalism, or what have you in physics or a related field, please get in touch. I know that the only way we get anything done is together. I'm interested in discussing and planning tactics from courses and workshops to community-building to more direct resistances in academic and industrial settings. Reach me at emma.m.mckay@gmail.com or @electroweak.

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