PLASMA SPRAYED SAMARIUM-COBALT PERMANENT MAGNETS

Book based on a
Homonymous Paper
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Music and Lyrics
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This work was incubated at Chicago Dramatists' Staging Science: Writing the Science Play, instructed by Kristin Idaszak.

THANK YOU

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Ambrose Cappuccio	Playwright
Deepthy Kishore	Playwright
Mike McGeever	Playwright
Frank Dana	Playwright
Lane Hedler	Playwright
Carrie S.	Playwright
Noreen	Playwright
Madhuri Shekar	Scenic Insight
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PLASMA SPRAYED SAMARIUM-COBALT PERMANENT MAGNETS

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ABSTRACT

Samarium-cobalt permanent magnets were fabricated by arc plasma spraying. This process involves the injection of relatively coarse powder particles into a high-temperature gas for melting and spraying onto a substrate. The technique is being investigated as an economical method for fabricating cobalt-rare earth magnets for advanced traveling wave tubes and cross-field amplifiers. Plasma spraying permits deposition of material at high rates over large areas with optional direct bonding to the substrate, and offers the ability to fabricate magnets in a variety of shapes and sizes. Isotropic magnets were produced with high coercivity and good reproducibility in magnetic properties. Post-spray thermal treatments were used to enhance the magnetic properties of sprayed deposits. Samarium-cobalt magnets, sprayed from samarium-rich powder and subjected to post-spray heat treatment, displayed energy products in excess of 9 million gauss-oersteds and coercive forces of approximately 6000 oersteds. Bar magnet arrays were constructed by depositing magnets on ceramic substrates.

INTRODUCTION

Two basic processes have been developed for preparing cobalt-rare earth magnets: (1) pressing and sintering including the optional use of a liquid phase; and (2) casting. Additional processes being investigated include sputtering[1] and plasma spraying.[2,3] Plasma spraying is a method for directly converting a powder into a solid magnet shape. Sprayed magnets, which are essentially isotropic magnetically, can be formed in various shapes and sizes as free-standing magnets or permanently bonded to substrates. Plasma spraying permits high deposition rates thus offering low cost potential. The process is being investigated as an economical method for fabricating samarium-cobalt magnets for advanced traveling wave tubes and cross-field amplifiers.

EXPERIMENTAL

In arc plasma spraying, an inert arc gas is continuously passed through an electric DC arc, located inside of a spray torch, for heating and ionization. The resulting ionized gas (plasma) leaving the torch

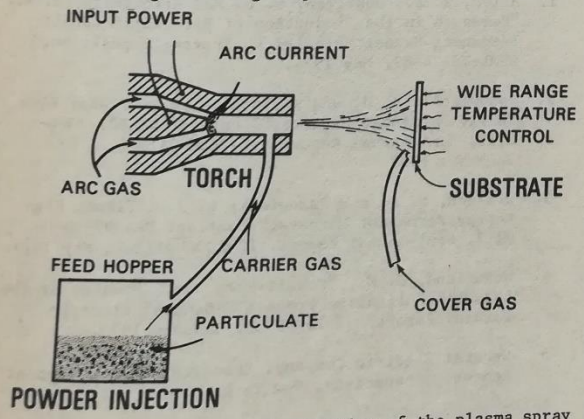

Fig. 1. Construction and operation of the plasma spray torch

nozzle resembles an open welding flame. Powder particles, transported in a carrier gas, are injected into the plasma stream for melting and spraying onto a substrate, as shown schematically in Figure 1. Process variables such as electrical energy to the torch, gas and powder flow rate, torch-to-substrate distance, and substrate temperature must be suitably controlled. For the processing of oxidation-sensitive rare earth-cobalt materials, plasma spray deposition should be conducted in a non-oxidizing atmosphere such as argon.

Most spray powders were prepared by pulverizing prealloyed ingots to a nominal average particle size of 20 μm. Several alloy compositions, covering the range 33.8 to 39.1 wt.% Sm-Co, were systematically studied over a range of process conditions. A limited number of magnets was also produced using reduction-diffusion (R-D) alloy powders[4] containing 37.4 and 38 wt.% Sm in two particle sizes, 3.5 μm and 17 μm.

Most test magnets were produced by depositing Sm-Co alloy onto the ends of a cluster of 0.25-inch diameter graphite rods. Sprayed deposits were ground circumferentially, removed from the rod, and lapped. Several of the resulting free-standing disks were stacked to form a cylindrical magnet for testing using a hysteresigraph. Test magnets were pulse magnetized in a 60 KOe magnetic field after which demagnetization curves were plotted. Many magnets were subsequently heat treated and aged at elevated temperature in inert gas atmosphere in order to enhance magnetic properties and then retested. Special bonded bar magnets were also produced in this study by depositing Sm-Co through an aperture mask onto a flat ceramic substrate.

RESULTS AND DISCUSSION

Magnets displaying the highest energy products and best overall magnetic properties to date were produced from Sm-Co alloy ingot powder containing 38 to 39 wt.% Sm as determined by wet analyses. The optimum composition of reduction-diffusion alloy powder for use in this process has not yet been determined. However, magnets sprayed from unmilled

Table I

PROPERTIES OF SPRAY FABRICATED MAGNETS

Process Conditions	A	B	C
Powder type	Ingot	Ingot	R-D
%Sm;μm	37.9;-74	39.1;-74	38;17
Arc gas, type;cfh	A;190	A;150	A;190
Torch power, kW	25.2	16.2	15.2
Distance, in.	2.5	3	1.5
Heat treatment, hr;°C	1.5;1040	4.5;1080	1.5;1030
Aging, hr;°C	16;950	16;950	None
Properties			
As Sprayed			
B_r, kG	4.69	4.48	ND
H_c, kOe	2.49	2.08	ND
iH_c, kOe	6.2	5.07	ND
BH_{max}, MGOe	2.8	2.2	ND
Heat Treated and Aged			
ρ, g/cc	ND	7.96	7.82
B_r, kG	6.0	6.19	5.45
H_c, kOe	5.86	5.84	5.31
iH_c, kOe	∿30.0	∿30.5	∿47.8
BH_{max}, MGOe	9.0	9.3	7.1

ND - not determined

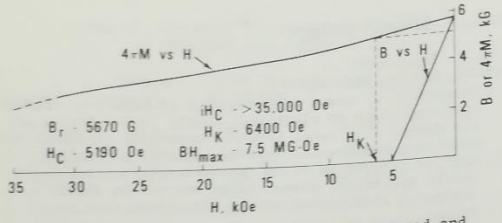

Fig. 2. Demagnetization curve for plasma-sprayed and heat-treated magnet

(~17μ) R-D powder were significantly better magnetically than those fabricated from milled (3.5μ) R-D powder. Properties of magnets recently produced from both ingot and R-D powders are presented in Table I together with the processing conditions employed for fabrication. The demagnetization curve for an earlier plasma-sprayed and heat treated magnet is shown in Figure 2.

The low B_r values of spray fabricated magnets are attributed to the isotropic nature of these materials. Attempts to enhance crystallographic orientation through the use of magnetic fields and temperature gradients have met with only limited success. However, the isotropic characteristic makes plasma-sprayed magnets suitable for use when extremely high magnetic fields are not required or when it is desired to magnetize in a particular direction without adversely affecting magnetic properties.

Oxygen, hydrogen and nitrogen content determined using the vacuum fusion procedure[5] for a magnet fabricated earlier from 38 wt.% Sm-Co ingot alloy powder showed 0.26 wt.% 0, ~13 ppm hydrogen and ~175 ppm nitrogen. After heat treatment at 1050°C for 4 hr., the magnet displayed the following properties: B_r, 5.25 kG; H_c, 4.56 kOe; $_{i}H_c$, 14.0 kOe; BH_{max}, 6.3 MGOe.

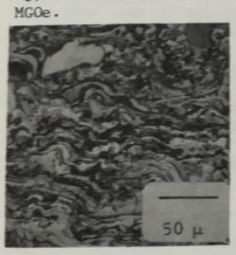

Fig. 3. Microstructure of as-sprayed Sm-Co magnet (bright field)

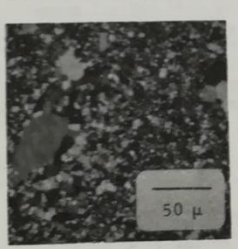

Fig. 4. Microstructure of sprayed Sm-Co magnet after heat treatment and aging (polarized light)

The microstructure of an "as-sprayed" Sm-Co magnet (Spec. A, Table I) is shown in Figure 3. It consists principally of elongated stringers, 2-3 μm thick and 50-200 μm long, aligned perpendicular to the spraying direction. At least four phases can be observed in the multiphase alloy: Sm_2Co_{17} (lightest), $SmCo_5$, Sm_2Co_7, and $SmCo_3$ (darkest). The microstructure of the same magnet after heat treatment and aging is shown in Figure 4. It consists principally of equiaxed grains of $SmCo_5$. Grain size range is 2-50 μm in diameter with most grains in the 2-10 μm range.

In this study, magnets have been fabricated in the shape of bars, tubes, rods, disks, plates, rings and arc segments as shown in Figure 5. Bar magnets were also directly bonded to ceramic substrates. Such bar arrays are being considered for use in advanced planar traveling wave tubes. The axial field profile of a magnet bar array containing 0.75x0.2x0.125 inch bar magnets on alumina substrate is shown in Figure 6.

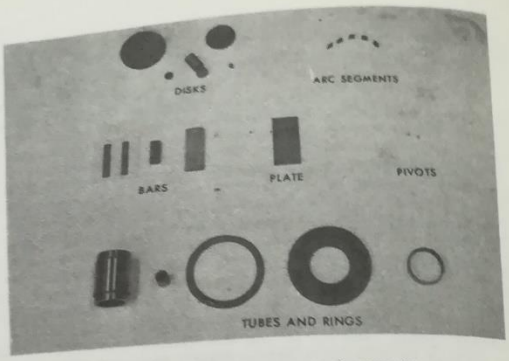

Fig. 5. Arc plasma-sprayed magnets

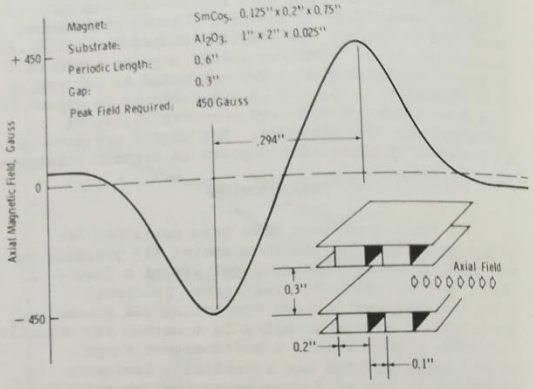

Fig. 6. Magnetic field profile of plasma-sprayed bar magnet array

ACKNOWLEDGMENT

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2. Janowiecki, R. J. and Willson, M. C., "Planar High Energy Permanent Magnets," Contract DAAB07-73-C-0112, Semi-Annual Report, TR-ECOM-0112-1, December 1973.

3. Willson, M. C. and Janowiecki R. J., "Planar High Energy Permanent Magnets," Contract DAAB07-73-C-0112, Semi-Annual Report, TR-ECOM-0112-2, May 1974.

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5. General Electric Company, Research and Development Center, Schenectady, New York.

SYNOPSIS

Samarium and Cobalt research together at Monsanto Research Corporation. All they do is choreograph magnetic dances. They feel at home because they have to. They're stuck in magnetization. All Cobalt could think about is the prealloyed ingot (gold bar). Samarium is wise and knows the tricks that corporations do to corrupt science.

CHARACTER BREAKDOWN

Character	Vocal Range	Gender	Age (maybe)
SAMARIUM A magnetic researcher.	Mezzo-Soprano	Any (Likely Woman)	62
COBALT A magnetic researcher.	Baritone	Any (Likely Man)	27

MUSICAL NUMBER

♬#	Title	Character(s)	Instrument(s)
1.	Arc		Piano|Vibraphone
2.	Spray	SAMARIUM|COBALT	Piano|Guitar

SET DESIGNS

Location	SET | props
Monsanto Research Corporation	LABORATORY|magnets|gas cannister|blowtorch spray bottle|ingot (gold bar)

Magnetization

[Monsanto Research Corporation]

[The laboratory holds magnets, a gas cannister, a blowtorch, a spray bottle, and hides an ingot (gold bar).]

(SAMARIUM stands on one side.)

(COBALT rests on the other side.)

[The storm brews.]

1. ARC (excerpt of "Catch Electrons" from *TOUR*)

(SAMARIUM and COBALT rush into action. They each pick up a magnet. They fluidly dance about. They may with one another.)

[The storm dampens.]

(SAMARIUM and COBALT slows down. They rush to their sides. They try to find an escape. They toss their magnets back to their original spots.)

(SAMARIUM grabs the ingot.)

(COBALT protests.)

(SAMARIUM places the ingot on the floor. They grab the gas cannister. They raise the gas cannister, preparing to smash the ingot.)

(COBALT grabs the blowtorch. They seemingly threaten SAMARIUM with the blowtorch.)

(SAMARIUM gently places the gas cannister on the floor.)

(COBALT swiftly swipes away the ingot.)

2. SPRAY (variant of "Meson Decay" from *TOUR*)

SAMARIUM

INGOT A U, LET GO COBALT.
OXIDATING ATMOSPHERE OUT.
THE WORLD'S MORE THAN ISOTROPIC.
CROSS FIELDS BY PLASMA SPRAYING, COBALT!

COBALT

MAGNET FABRICATION.
RATES, HIGH DEPOSITION.
HEAT, IONIZATION.
DEMAGNETIZATION.
SAMARITAN,
INGOT KEEPS ME SPUTTERING.
SAM— SAMARIUM.

SAMARIUM

WANT TO BE FREE STANDING, COBALT?
OR BE PERMANENTLY BONDED?
FINE WITH ELEVATED TEMP-TURES.

(Motioning to the gas cannister.)

SAMARIUM (cont.)

PASS SUBSTRATES BY PLASMA SPRAY, COBALT!

(Directing far beyond.)

COBALT

OPT-MAL COMPOSITION.
NO DETERMINATION.
MAY ALLOY REDUCTION.
MAY ALLOY DIFFUSION.
SOME THINGS CAN’T CHANGE,
INGOT KEEPS US CONNECTED.
SAM— SAMARIUM.

SAMARIUM

IN YOUR HEAD, ANY NUTS AND BOLTS?
SCIENTIFIC PRODUCTION, STASIS.
GET NOWHERE 'CAUSE OF YOU INGOTS.

(COBALT reluctantly hands the ingot to SAMARIUM.)

FINALLY, AN AMPLIFIER, COBALT.

Demagnetization

(SAMARIUM places the ingot on the floor.)

(COBALT distraughtly eyes the laboratory.)

PLEASE PROCESS CONDITIONS, COBALT.

(Grabbing the gas cannister.)

THERE ARE HIGHER MAGNETIC FIELDS.

(Smashing the ingot into powder with the gas cannister.)

SAMARIUM (cont.)

CONCLUSIVE, WE DEMAGNETIZE.

(Grabbing the spray bottle.)

WE'RE RARE EARTH AND EARTH IS RARE, COBALT.

(Dumping the powder into the spray bottle.)

SPRAY?

(Relinquishing the spray bottle.)

(COBALT honourably takes the spray bottle. They spray the walls.)

(SAMARIUM grabs the blowtorch. They ignite the blowtorch.)

Fin

Demagnetization (alternative)

(SAMARIUM honourably hands the spray bottle to COBALT.)

(COBALT sprays the walls.)

COBALT

~~T~~hey're going to demagnetize us, you know~~?~~

(Motioning towards a Monsanto emblem.)

SAMARIUM

~~I~~ am counting on our curve to be conclusive~~.~~

(Turning on the blowtorch.)

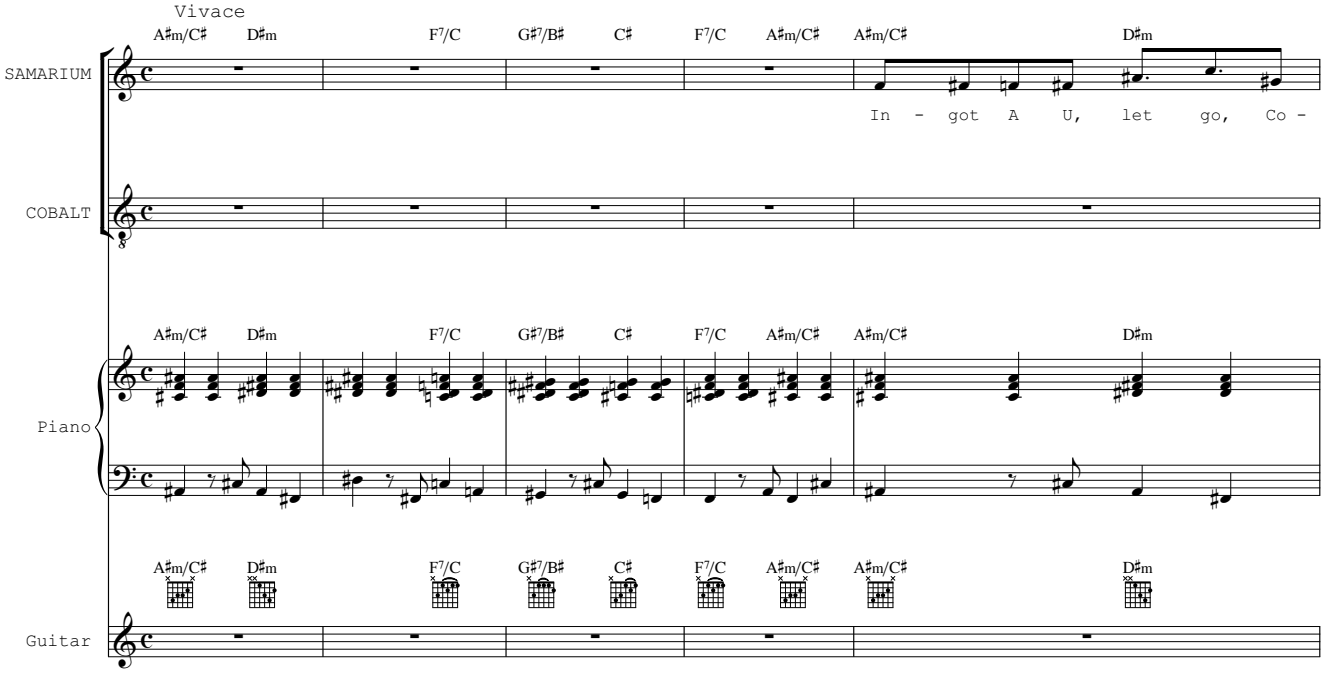
Fin

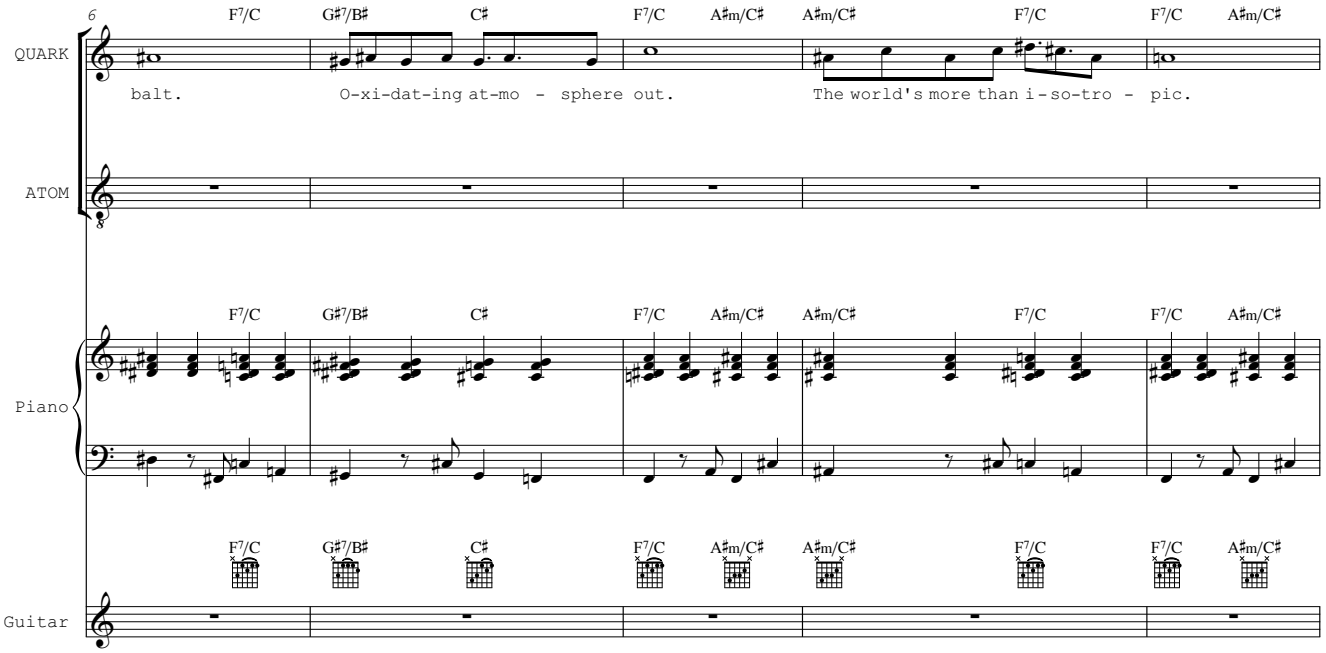
Score

$_{2}$SPRAY

Plasma Sprayed Samarium-Cobalt Permanent Magnets

DAVID QUANG PHAM





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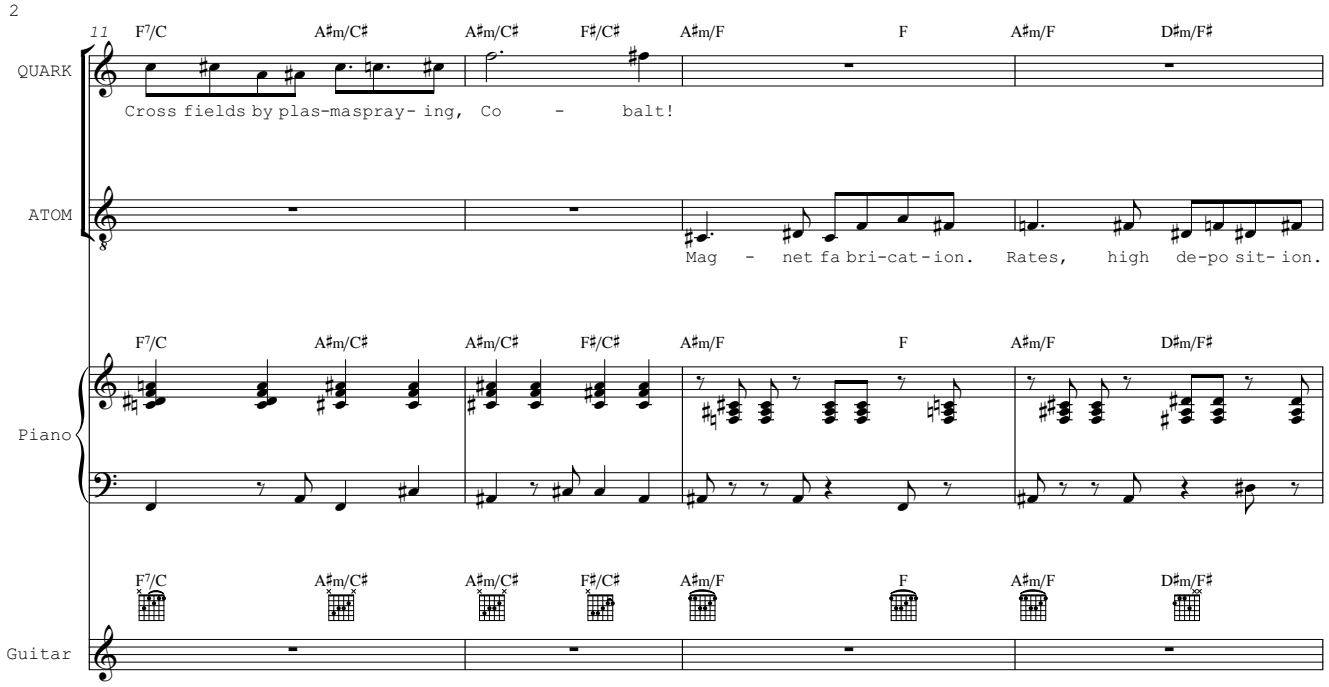
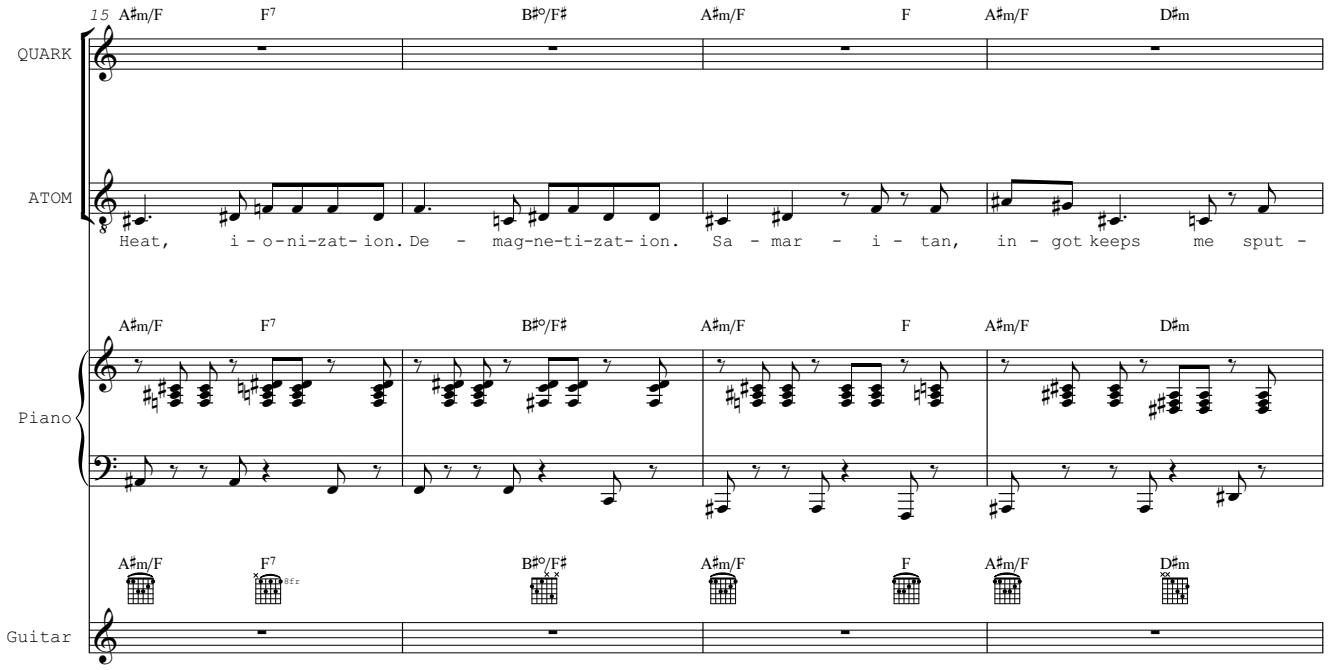

11
F7/C
A♯m/C♯
A♯m/C♯
F♯/C♯
A♯m/F
F
A♯m/F
D♯m/F♯
QUARK
Cross fields by plas-maspray- ing, Co - balt!
ATOM
Mag - net fa bri-cat-ion. Rates, high de-po sit- ion.
Piano
Guitar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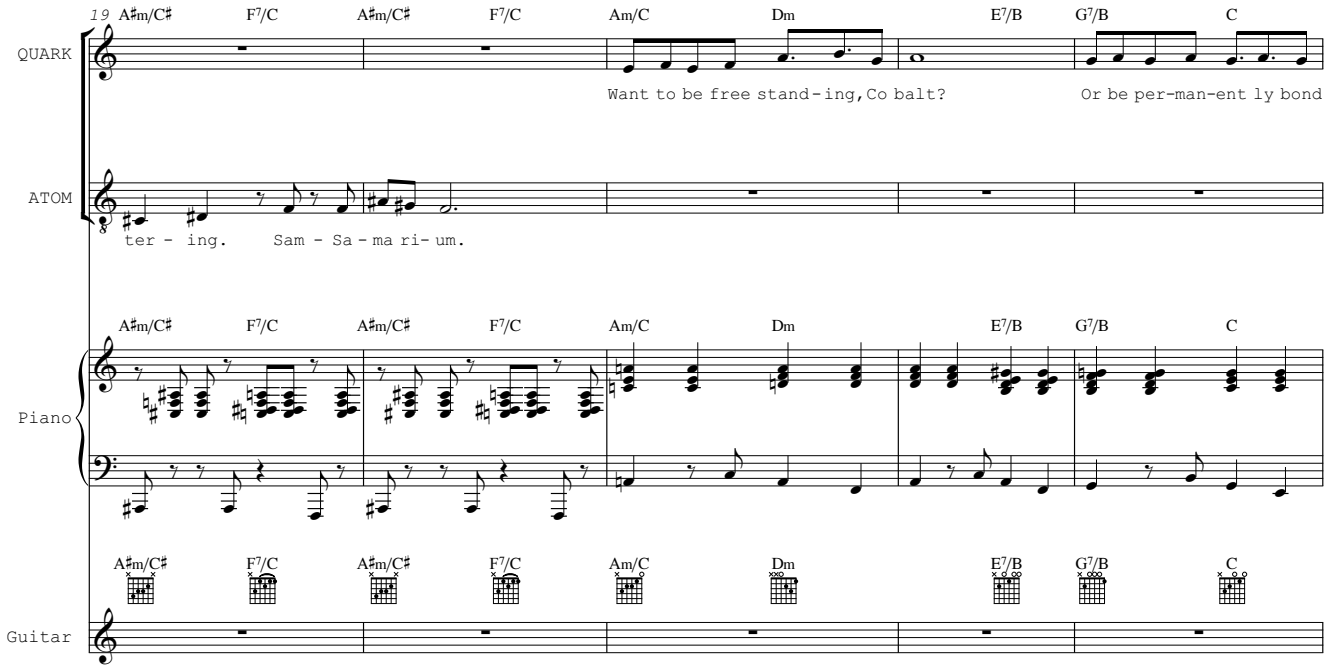
A♯m/F
F7
B♯°/F♯
A♯m/F
F
A♯m/F
D♯m
QUARK
ATOM
Heat, i - o-ni-zat- ion. De - mag-ne-ti-zat- ion. Sa - mar - i - tan, in - got keeps me sput -
Piano
Guitar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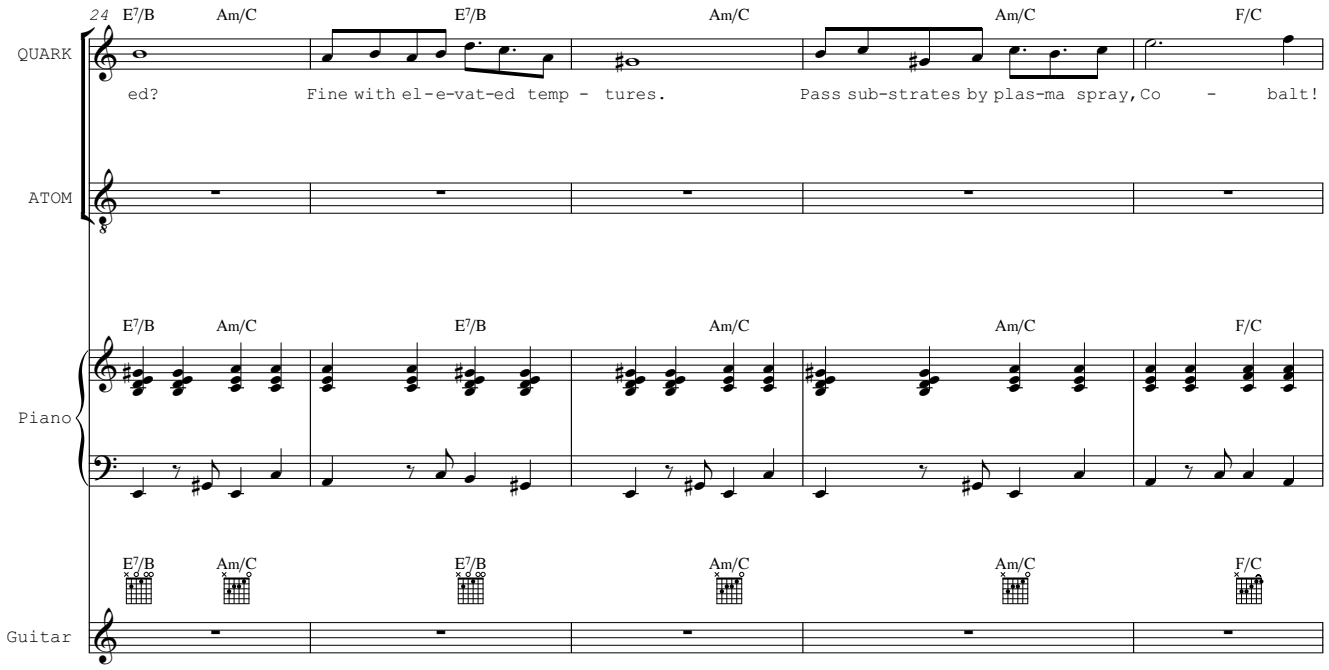
A♯m/C♯ F7/C A♯m/C♯ F7/C Am/C Dm E7/B G7/B C
QUARK
Want to be free stand-ing, Co balt? Or be per-man-ent ly bond
ATOM
ter - ing. Sam - Sa - ma ri- um.
Piano
Guitar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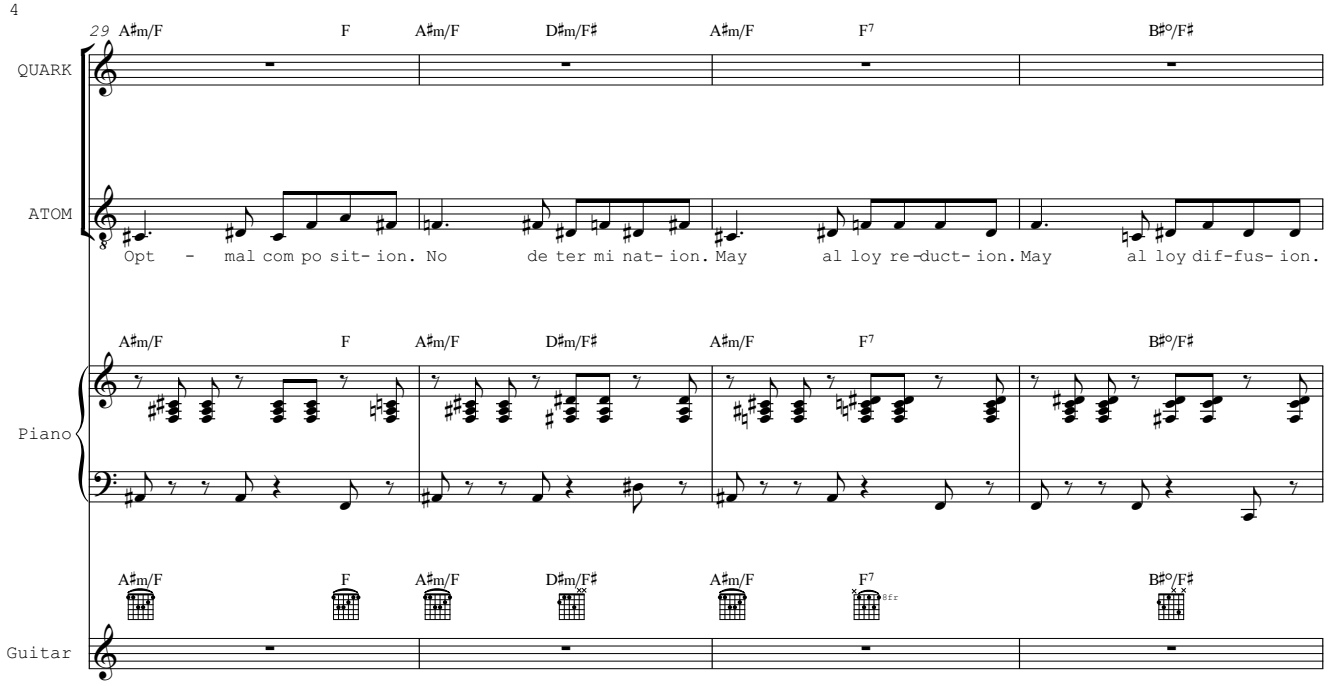
E7/B Am/C E7/B Am/C Am/C F/C
QUARK
ed? Fine with el-e-vat-ed temp - tures. Pass sub-strates by plas-ma spray, Co - balt!
ATOM
Piano
Guitar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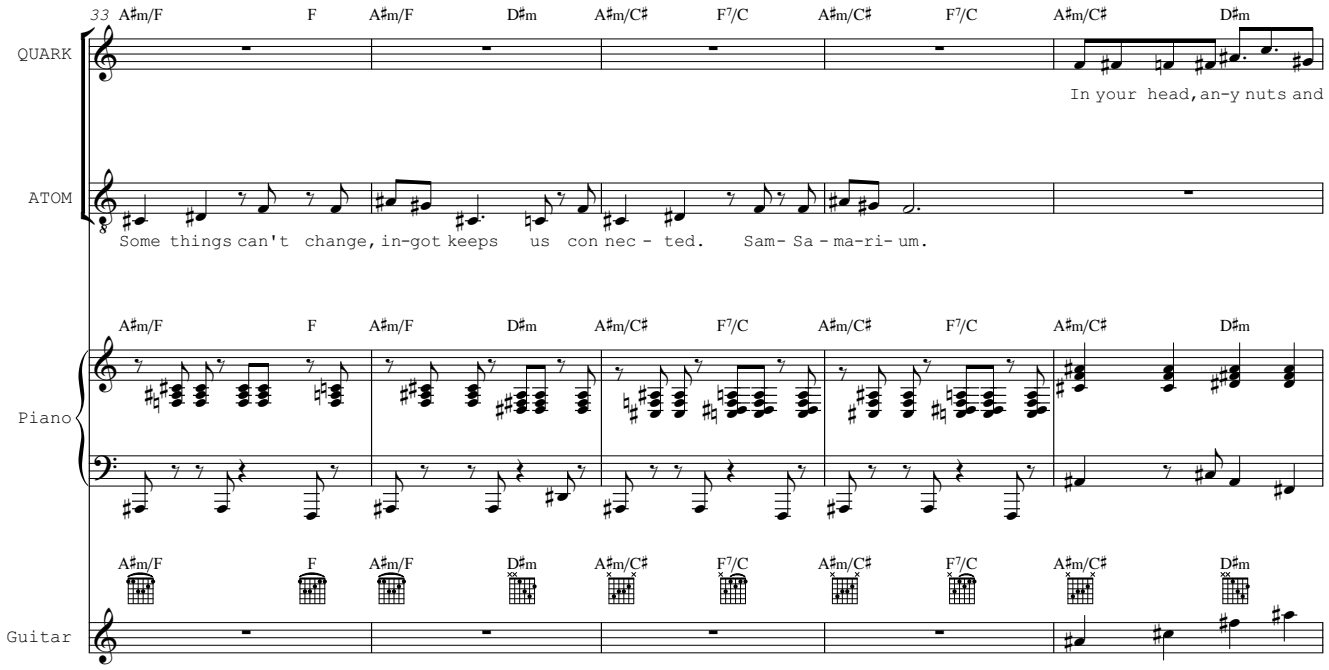
A♯m/F
F
A♯m/F
D♯m/F♯
A♯m/F
F7
B♯°/F♯
QUARK
ATOM
Opt - mal com po sit- ion. No de ter mi nat- ion. May al loy re-duct- ion. May al loy dif-fus- ion.
Piano
Guitar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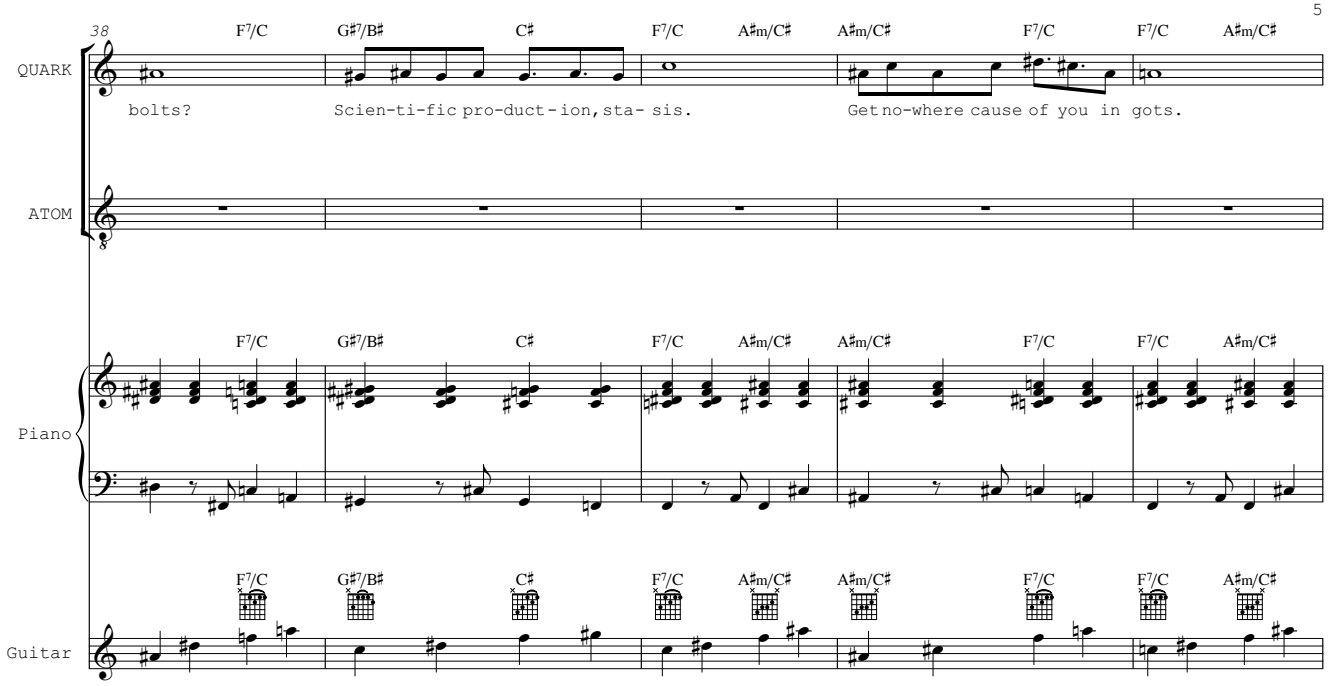
A♯m/F
F
A♯m/F
D♯m
A♯m/C♯
F7/C
A♯m/C♯
F7/C
A♯m/C♯
D♯m
QUARK
In your head, an-y nuts and
ATOM
Some things can't change, in-got keeps us con nec - ted. Sam- Sa - ma-ri- um.
Piano
Guitar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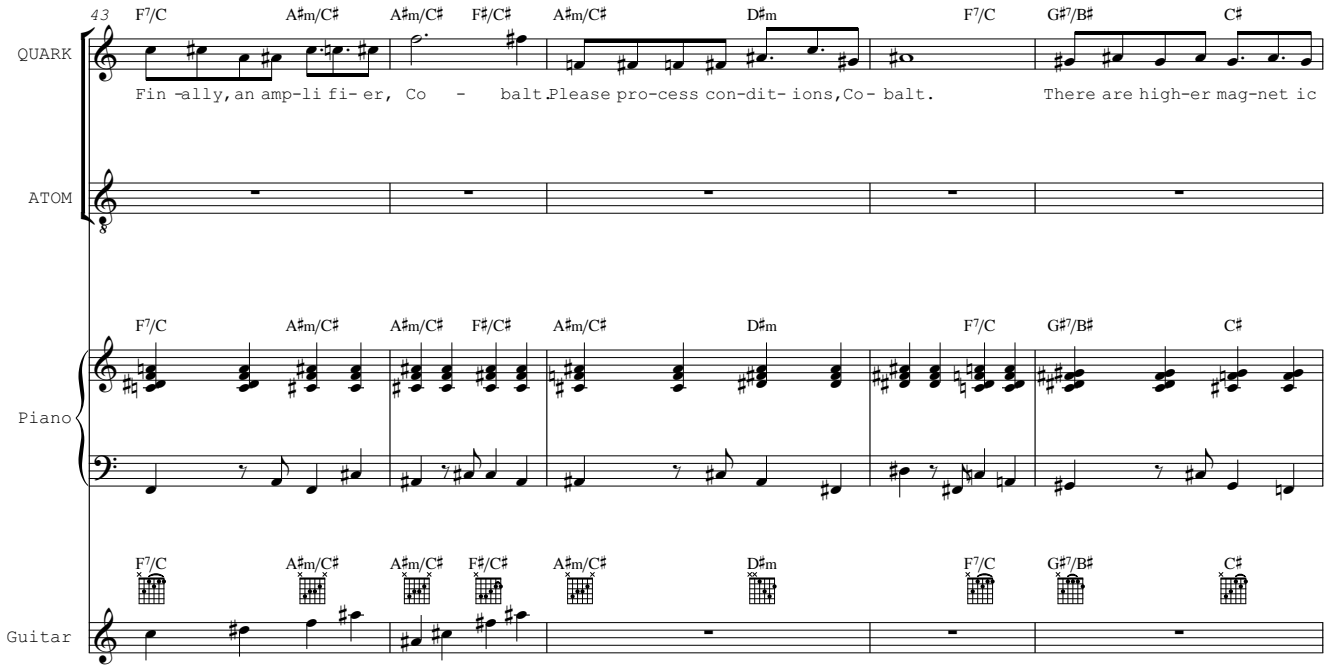
F7/C
G♯7/B♯
C♯
F7/C
A♯m/C♯
A♯m/C♯
F7/C
F7/C
A♯m/C♯
QUARK
bolts?
Scien-ti-fic pro-duct-ion, sta- sis.
Get no-where cause of you in gots.
ATOM
Piano
Guitar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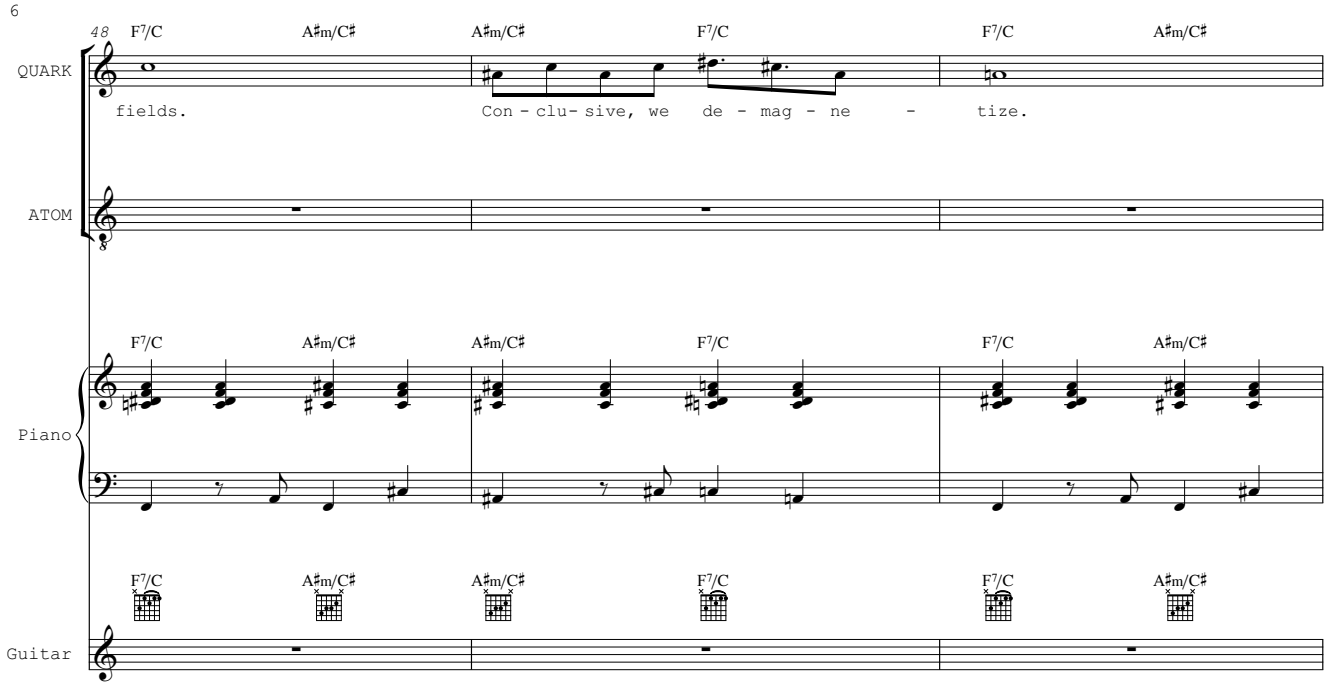
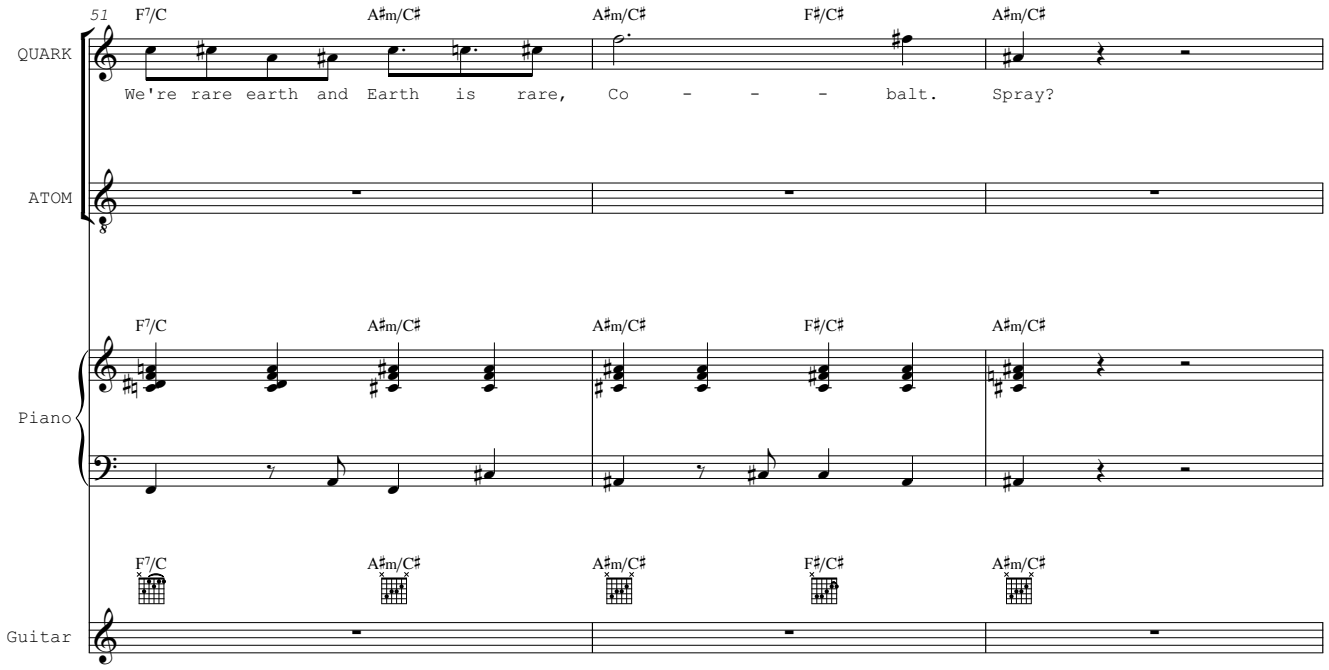
F7/C
A♯m/C♯
A♯m/C♯
F♯/C♯
A♯m/C♯
D♯m
F7/C
G♯7/B♯
C♯
QUARK
Fin -ally, an amp-li fi- er, Co - balt. Please pro-cess con-dit- ions, Co- balt.
There are high-er mag-net ic
ATOM
Piano
Guitar


48
F7/C
A♯m/C♯
A♯m/C♯
F7/C
F7/C
A♯m/C♯
QUARK
fields.
Con - clu- sive, we de - mag - ne - tize.
ATOM
Piano
Guitar


51
F7/C
A♯m/C♯
A♯m/C♯
F♯/C♯
A♯m/C♯
QUARK
We're rare earth and Earth is rare, Co - - - balt. Spray?
ATOM
Piano
Guitar