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(54) Title: MAGNETIC LEVITATION SYSTEM

(57) Abstract: A magnetic levitation system is described, including a first and second magnets having surfaces of their like-poles facing each other; and a container disposed between the first and second magnets' like poles and containing a solution including a paramagnetic complex in a non-aqueous solvent, where the paramagnetic complex includes a paramagnetic metal and at least one ligand that coordinates to the paramagnetic metal via electron donation. Methods of separating a mixture of solid compounds, and/or identifying, confirming, and/or predicting the composition of the mixture, are also described.

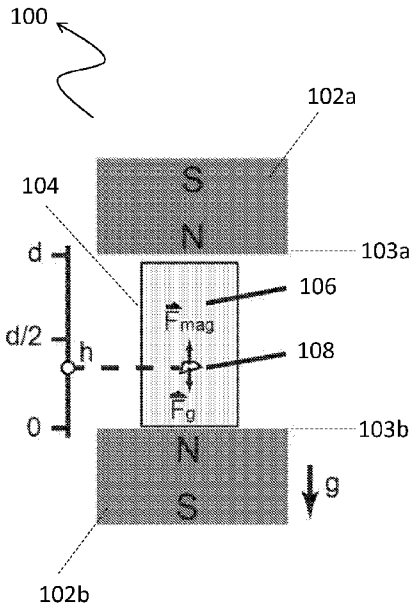

FIG. 1A

[Continued on next page]

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TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

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MAGNETIC LEVITATION SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Patent Application No. 62/819,382, filed March 15, 2019, which is hereby incorporated by reference in its entirety.

INCORPORATION BY REFERENCE

[0002] All patents, patent applications and publications cited herein are hereby incorporated by reference in their entirety in order to more fully describe the state of the art as known to those skilled therein as of the date of the invention described therein.

FIELD OF THE INVENTION

[0003] The present disclosure relates generally to the field of analytical chemistry. More particularly, the present disclosure relates to density analysis.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

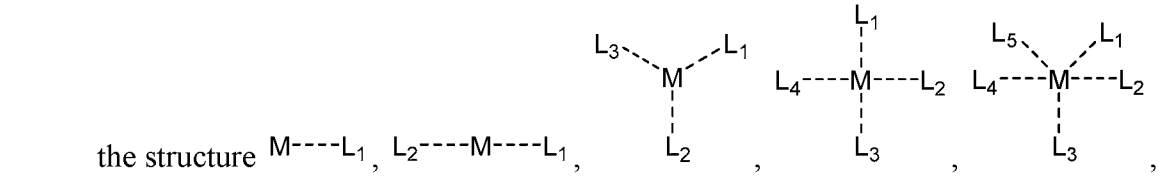
[0004] The present invention was made with government support from the Department of Energy, Office of Basic Energy Sciences, Division of Materials Sciences and Engineering (Award No. ER45862), and from Department of Defense, Defense Advanced Research Projects Agency (Award No. W911NF-18-2-0030). The U.S. Government has certain rights in the invention.

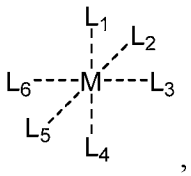
SUMMARY OF THE INVENTION

[0005] In one aspect, a magnetic levitation system includes:

a first and second magnets having surfaces of their like-poles facing each other; and

a container disposed between the first and second magnets' like poles and containing a solution including a paramagnetic complex in a non-aqueous solvent; where the paramagnetic complex includes a paramagnetic metal and at least one ligand that coordinates to the paramagnetic metal via electron donation.

[0006] In any one of the embodiments described herein, the paramagnetic complex has the structure 



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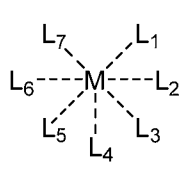

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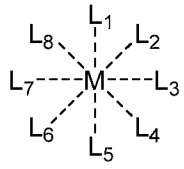
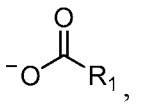


, where M is a paramagnetic metal and L_1, L_2, L_3, L_4, L_5, L_6, L_7, and L_8 are ligands that coordinate to the paramagnetic metal via electron donation.

[0007] In any one of the embodiments described herein, L_1, L_2, L_3, L_4, L_5, L_6, L_7, and L_8 are independently selected from the group consisting of substituted or unsubstituted phosphine oxides, oxazoles, imidazoles, pyridines, diamines, bipyridines, phenanthrolines, diketonates, malonamides, malonates, β-ketoesters, β-ketoamides, carboxylates, dicarboxylates, and ethylenediaminetetraacetic acid.

[0008] In any one of the embodiments described herein, two or more of L_1, L_2, L_3, L_4, L_5, L_6, L_7, and L_8 are covalently bonded to a substituent group consisting of 1-20 carbon atoms.

[0009] In any one of the embodiments described herein, at least one of L_1, L_2, L_3, L_4, L_5, L_6, L_7, and L_8 includes


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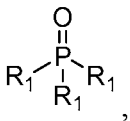

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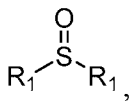

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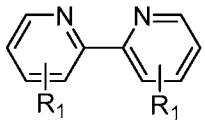

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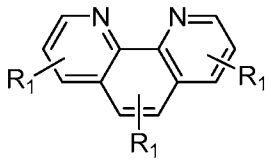
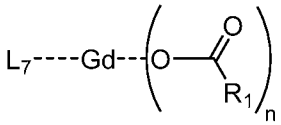


, where each occurrence R_1 is independently H, (C_1-C_{20})alkyl, (C_2-C_{20})alkenyl, (C_2-C_{20})alkynyl, (C_3-C_{10})cycloalkyl, (C_6-C_{10})aryl, or (C_6-C_{10})heteroaryl, each of which is optionally substituted with one or more substituents selected from the group consisting of halogen, R^a, OR^a, NR^aR^b, COR^a, CO_2R^a, or $CONR^aR^b$; and where R^a and R^b are independently selected from the group consisting of hydrogen and (C_1-C_6)alkyl.

[0010] In any one of the embodiments described herein, the paramagnetic complex has the structure


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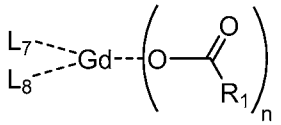

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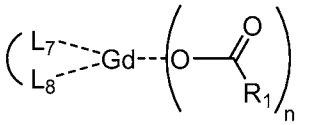

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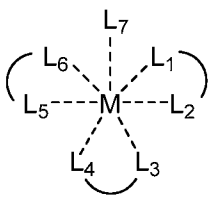

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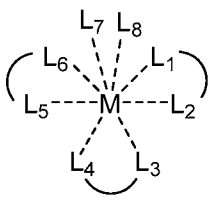

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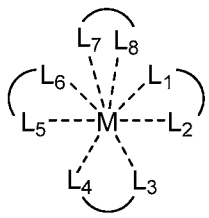
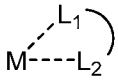
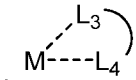
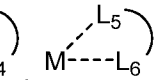
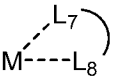
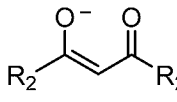
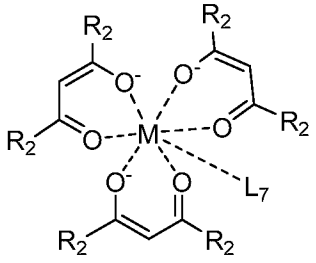
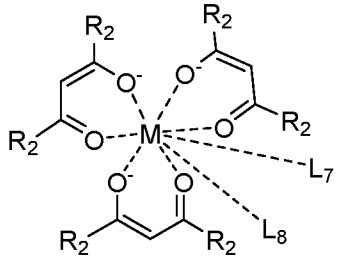
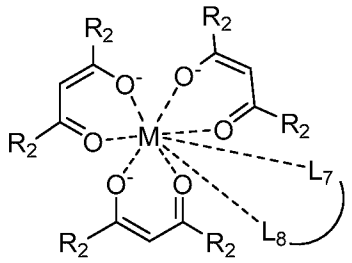
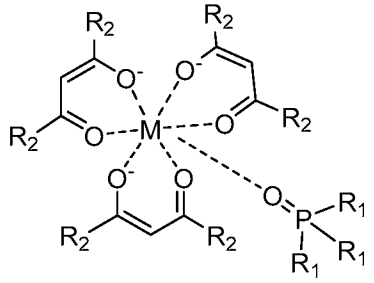
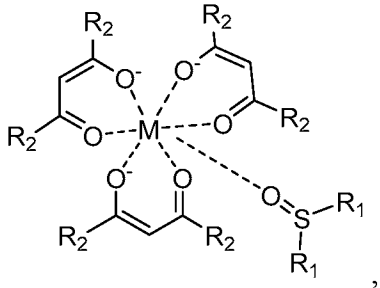
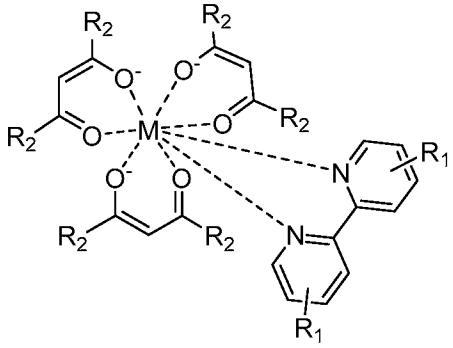
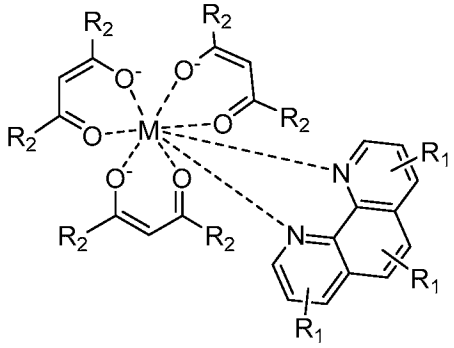


, where n is an integer from 1-7 and where "⌒" denotes the group consisting of 1-20 carbon atoms.

[0011] In any one of the embodiments described herein,  ,  ,  , and  are independently selected from the group consisting of 2,2'-dipyridyl, optionally substituted with one or more R_1, 1,10-phenanthrenyl, optionally substituted with one or more R_1, and  , where each occurrence of R_2 is independently H, (C_1-C_{20})alkyl, (C_2-C_{20})alkenyl, (C_2-C_{20})alkynyl, (C_3-C_{10})cycloalkyl, (C_6-C_{10})aryl, or (C_6-C_{10})heteroaryl, each of which is optionally substituted with one or more substituents selected from the group consisting of halogen, R^a, OR^a, NR^aR^b, COR^a, CO_2R^a, or $CONR^aR^b$; and where R^a and R^b are independently selected from the group consisting of hydrogen and (C_1-C_6)alkyl.

[0012] In any one of the embodiments described herein, the paramagnetic complex has the structure,  ,  , or  .

[0013] In any one of the embodiments described herein, the paramagnetic complex has the structure  ,  ,  , or  .

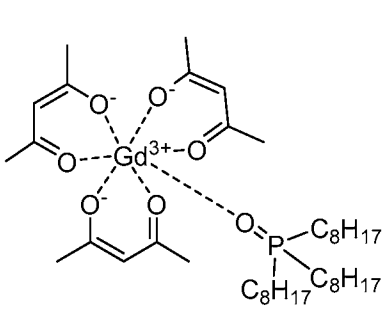
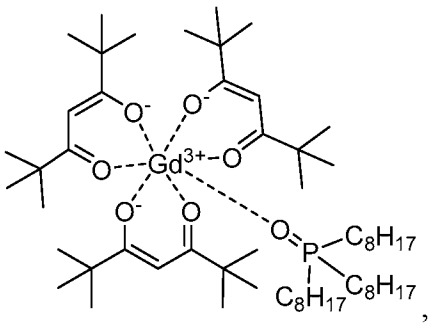
[0014] In any one of the embodiments described herein, each occurrence of R_1 and R_2 is independently $(C_1\text{-}C_{10})$alkyl or $(C_6\text{-}C_{10})$aryl.

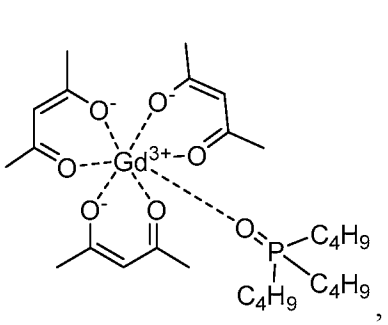
[0015] In any one of the embodiments described herein, each occurrence of R_1 and R_2 is independently methyl, ethyl, propyl, butyl, pentyl, hexyl, heptyl, octyl, nonyl, decyl, phenyl, or isomers thereof.

[0016] In any one of the embodiments described herein, each occurrence of R_1 and R_2 is independently methyl, butyl, tert-butyl, octyl, or phenyl.

[0017] In any one of the embodiments described herein, M is selected from the group consisting of scandium, titanium, vanadium, chromium, manganese, iron, cobalt, nickel, cerium, praseodymium, neodymium, europium, gadolinium, terbium, dysprosium, copper, holmium, erbium, thulium, and lanthanum.

[0018] In any one of the embodiments described herein, M is gadolinium.

[0019] In any one of the embodiments described herein, the paramagnetic complex is  ,  ,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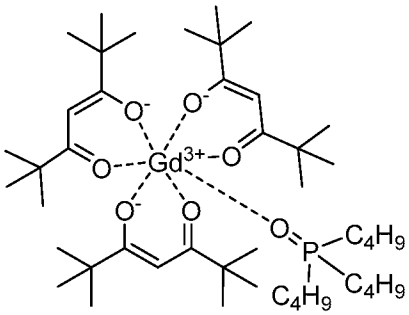
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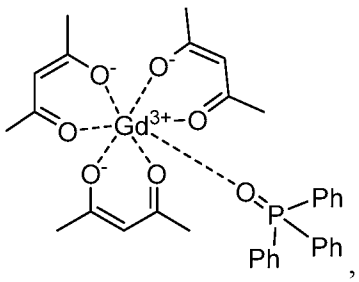
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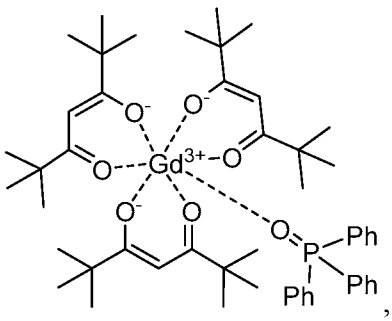
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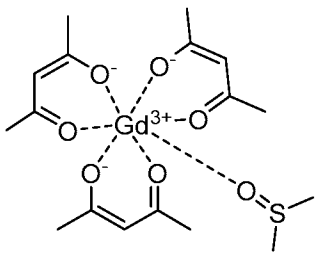
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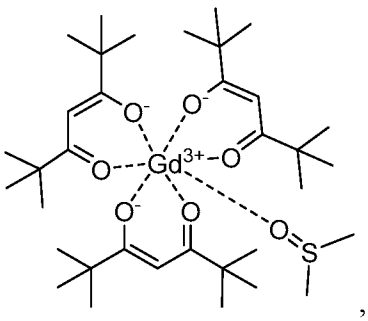
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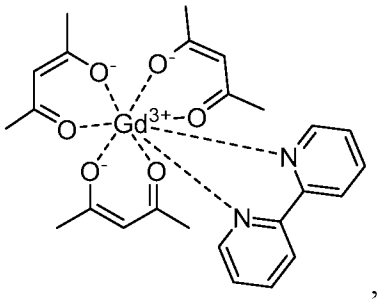
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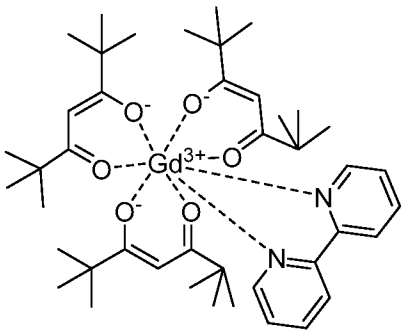
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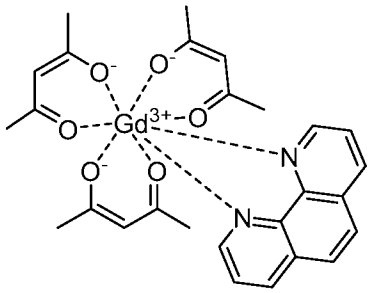
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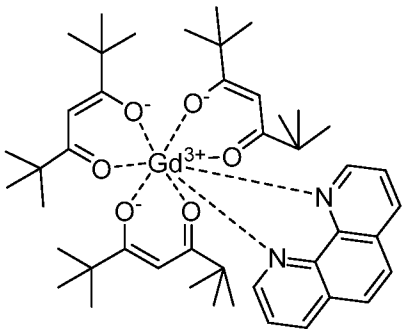
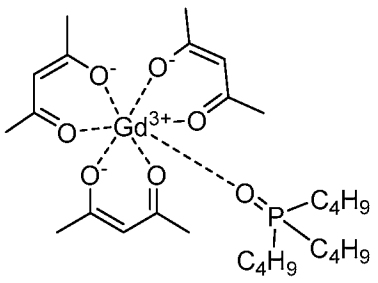
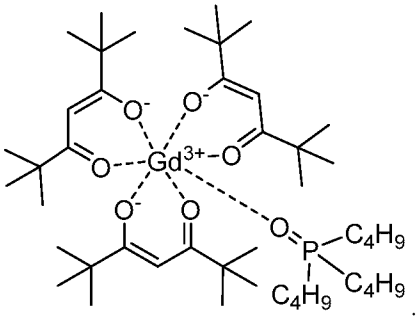

or .

[0020] In any one of the embodiments described herein, the paramagnetic complex is


or

.

[0021] In any one of the embodiments described herein, the solvent is selected from the group consisting of acyclic and cyclic hydrocarbons, acyclic and cyclic halo- or per-halo hydrocarbons, aromatic hydrocarbons, acyclic and cyclic ethers, and acyclic and cyclic aldehydes, ketones, esters, amides, sulfides, sulfoxides, and sulfones, and a combination thereof.

[0022] In any one of the embodiments described herein, the solvent is pentane, hexane, heptane, octane, nonane, decane, undecane, dodecane, tetrachloroethylene, carbon tetrachloride, dichloromethane, trichloromethane, diethyl ether, tetrahydrofuran, ethyl acetate, butyl acetate, or a combination thereof.

[0023] In any one of the embodiments described herein, the solvent is hexane, tetrachloroethylene, or a combination thereof.

[0024] In any one of the embodiments described herein, the solvent is tetrachloroethylene.

[0025] In any one of the embodiments described herein, the system further includes a camera, or a light source to illuminate the container, or both.

[0026] In any one of the embodiments described herein, the container is an open or closed vessel capable of holding the solution.

[0027] In any one of the embodiments described herein, the container is made from a glass, a plastic, a polymer, a ceramic, one or more plant-based fibers in a polymer matrix, one or more plant-based fibers in a ceramic matrix, an aerogel, a gel including polar or apolar solvents, a non-ferromagnetic, non-ferrimagnetic, or non-paramagnetic metal, or a combination thereof.

[0028] In any one of the embodiments described herein, the container is a cuvette, jar, test tube, centrifuge tube, or capillary tube.

[0029] In any one of the embodiments described herein, the container is a cuvette.

[0030] In any one of the embodiments described herein, the first and second magnets are each independently selected from the group consisting of a permanent magnet, an electromagnet, and a superconducting magnet.

[0031] In any one of the embodiments described herein, the first and second magnets are permanent magnets.

[0032] In any one of the embodiments described herein, the first and second magnets are each independently neodymium magnets, samarium-cobalt magnets, ferrite magnets, or Alnico magnets.

[0033] In any one of the embodiments described herein, the first and second magnets are each independently shaped as a block, a cylinder, a sphere, a disc, or a ring.

[0034] In another aspect, a method of analyzing a sample including one or more solid compounds, the method including:

(a) providing the magnetic levitation system of any one of claims 1-29;

(b) depositing the sample in the solution; and

(c) allowing each of the solid compounds in the sample to migrate to a position in the container indicative of its density.

[0035] In any one of the embodiments described herein, the method further includes

(d) analyzing one or more of the solid compounds to determine or confirm its identity.

[0036] In any one of the embodiments described herein, step (d) includes positioning the container such that one or more of the compounds contact the wall of the container and analyzing said compound(s) through the wall of the container using a spectrometer.

[0037] In any one of the embodiments described herein, step (d) includes removing the one or more solid compounds from the container.

[0038] In any one of the embodiments described herein, the one or more solid compounds are removed using a pipette, a siphon, a spoon, a spatula, or a small basket.

[0039] In any one of the embodiments described herein, the analysis includes a technique selected from the group consisting of Fourier transform infrared spectroscopy with attenuated total reflectance, mass spectrometry, nuclear magnetic resonance spectroscopy, Raman spectroscopy, X-ray diffractometry, capillary electrophoresis, gas chromatography, ion-mobility spectrometry, liquid chromatography, microcrystalline tests, supercritical fluid chromatography, thin layer chromatography, ultraviolet/visible spectroscopy, microscopy, visual examination, colorimetric tests, fluorescence spectroscopy, immunoassays, melting point analysis, pharmaceutical package inserts, and combinations thereof.

[0040] In any one of the embodiments described herein, the technique includes a portable or handheld device.

[0041] In any one of the embodiments described herein, the technique is Fourier transform infrared spectroscopy with attenuated total reflectance, Raman spectroscopy, mass spectrometry, X-ray diffractometry, a colorimetric test, or a combination thereof.

[0042] In any one of the embodiments described herein, the Raman spectroscopy is conducted using a portable or handheld device.

[0043] In any one of the embodiments described herein, the sample is a crystalline or amorphous sample.

[0044] In any one of the embodiments described herein, the sample includes one or more controlled substances, adulterants, diluents, or a combination thereof.

[0045] In any one of the embodiments described herein, the sample includes fentanyl, acetyl fentanyl, benzyl fentanyl, carfentanyl, cocaine, heroin, oxycodone, methamphetamine, cannabinoids, lysergic acid diethylamide, methaqualone, methadone, hydromorphone, Ritalin, Adderall, peyote, 3,4-methylenedioxymethamphetamine, acetaminophen, caffeine, diltiazem, dipyrone/metamizole, lidocaine, hydroxyzine, levamisole, papaverine, procaine, phenacetin, dimethyl sulfone, D-fructose, D-glucose, α-lactose, D-mannitol, sodium carbonate, starch, including potato starch, sucrose, talc, quinine, butylated hydroxytoluene, hypromellose, polyethylene glycol, polyethylene oxide, magnesium stearate, titanium dioxide, an isomer thereof, a salt thereof, a combination thereof.

[0046] In any one of the embodiments described herein, the salt is a sodium, aluminum, potassium, calcium, hydrochloride, citrate, nitrate, sulfate, acetate phosphate, diphosphate, maleate, mesylate, tartrate, or gluconate salt.

[0047] In any one of the embodiments described herein, the salt is a hydrochloride salt.

[0048] In any one of the embodiments described herein, the sample includes a salt of fentanyl or caffeine.

[0049] In any one of the embodiments described herein, the one or more compounds are present in the sample between 0.01 and 100 weight percent.

[0050] In any one of the embodiments described herein, the one or more compounds are present in the sample between 0.01 and 10 weight percent.

[0051] In any one of the embodiments described herein, the method further includes:

(e) generating a profile of the position of the one or more compounds relative to the container; and

(f) generating a database including a plurality of profiles, each of which corresponds to a known solid compound or a known mixture of solid compounds.

[0052] In any one of the embodiments described herein, the profile of the sample and the profiles of the database are determined at a plurality of time points after the sample is deposited in the solution in step (b).

[0053] In any one of the embodiments described herein, the method further includes:

(g) comparing the profile of the sample to the profiles in the database.

[0054] In any one of the embodiments described herein, step (g) further includes determining the identity of the compound based on the comparison.

[0055] In any one of the embodiments described herein, step (g) further includes:

using a computer to calculate the distances between the generated profile of the sample and the profiles in the database to identify a profile in the database within a minimum distance to the generated profile; where the distance is a Euclidian or Mahalanobis distance.

[0056] In any one of the embodiments described herein, the profile in the database further includes the source of the known solid compound or the known mixture of solid compounds and step (g) further includes determining the source of the sample.

[0057] In any one of the embodiments described herein, step (g) further includes determining the particle size or the mixture of particle sizes of the compound.

[0058] In any one of the embodiments described herein, the profile in the database further includes a source of the compound and step (g) further includes determining the source of the sample.

[0059] In any one of the embodiments described herein, the method includes obtaining and processing spectroscopic, spectrometric, chromatographic, colorimetric, microscopic, photographic, or visual signals of the one or more solid compounds at a position in the container before, at predetermined times during migration, and after migration.

[0060] In any one of the embodiments described herein, the method includes obtaining and processing microscopic or photographic images of the one or more solid compounds at a position in the container before, at predetermined times during migration, and after migration.

[0061] In any one of the embodiments described herein, the light intensity of one or more portions of the image before, at predetermined times during migration, and after migration is measured.

[0062] In any one of the embodiments described herein, the signals, images, or light intensity measurements of the container are processed by using dynamic time warping, barycenter averaging, machine learning, or a combination thereof.

[0063] In any one of the embodiments described herein, the machine learning includes deep neural networks.

[0064] In any one of the embodiments described herein, the machine learning includes supervised deep learning to train a convolutional neural network on hundreds-to-thousands of signals, images, or light intensity measurements.

[0065] In any one of the embodiments described herein, the analysis of unknown mixtures includes inputting one or more generated signals, images, or light intensity measurements into the trained convolutional neural network and obtaining an output of the identity of the mixture.

BRIEF DESCRIPTION OF THE DRAWINGS

[0066] The invention is described with reference to the following figures, which are presented for the purpose of illustration only and are not intended to be limiting. In the Drawings:

[0067] FIG. 1A shows a schematic diagram of a device for magneto-Archimedes levitation ("magnetic levitation" or "MagLev"), according to one or more embodiments.

[0068] FIG. 1B shows the magnetic field between the magnets of the MagLev device, according to one or more embodiments.

[0069] FIG. 1C shows the magnetic force a sample particle experiences when suspended in a paramagnetic solution and placed in the magnetic field of FIG. 1B, according to one or more embodiments.

[0070] FIG. 2A shows a MagLev device, according to one or more embodiments.

[0071] FIG. 2B shows a custom-made plastic cuvette filled with paramagnetic solution sitting in the MagLev device of FIG. 2A, according to one or more embodiments.

[0072] FIG. 3 shows FTIR-ATR spectra of $Gd(DPM)_3TOPO$ and $Gd(acac)_3TOPO$, according to one or more embodiments.

[0073] FIG. 4 shows separation of powdered mixtures of lidocaine·HCl and caffeine, according to one or more embodiments.

[0074] FIG. 5 shows a ^1H NMR spectrum of $Gd(DPM)_3TOPO$ used to measure its magnetic susceptibility, according to one or more embodiments.

[0075] FIG. 6 shows a ^1H NMR spectrum of $Gd(acac)_3TOPO$ used to measure its magnetic susceptibility, according to one or more embodiments.

[0076] FIG. 7A shows calibration of a MagLev device and its use to determine the density of levitating fractions, according to one or more embodiments.

[0077] FIG. 7B shows standard curves measured with glass bead density standards in solutions of $Gd(DPM)_3TOPO$, according to one or more embodiments.

[0078] FIG. 7C shows the standard curve measured with glass bead density standards in a solution of $Gd(acac)_3TOPO$, according to one or more embodiments.

[0079] FIG. 8 shows a schematic diagram of a custom cuvette, according to one or more embodiments.

[0080] FIG. 9 shows separation and extraction of the separate fractions of a powdered mixture of fentanyl-laced heroin in a MagLev device, according to one or more embodiments.

[0081] FIG. 10A shows an image taken after 30 minutes of separation by MagLev of a powdered mixture of fentanyl-containing heroin, according to one or more embodiments.

[0082] FIG. 10B shows the unprocessed image of FIG. 10A, according to one or more embodiments.

[0083] FIG. 10C shows FTIR-ATR spectra measured for the powdered mixture of FIG. 10A pre- and post-separation, according to one or more embodiments.

[0084] FIG. 11A shows time-lapse photographs of the separation of mixtures of powdered illicit drugs, adulterants, and dilutants using MagLev, according to one or more embodiments.

[0085] FIG. 11B shows the unprocessed images of FIG. 11A, according to one or more embodiments.

[0086] FIG. 12A shows MagLev separation of a mixture of lidocaine·HCl and caffeine, according to one or more embodiments.

[0087] FIG. 12B shows MagLev separation of powdered mixtures of lidocaine·HCl and caffeine in different proportions, according to one or more embodiments.

[0088] FIG. 12C shows scanning electron micrographs of crystals of pure lidocaine·HCl and caffeine, according to one or more embodiments.

[0089] FIG. 12D shows the projected, two-dimensional areas of the levitating fractions of lidocaine·HCl and caffeine, and their combined area, plotted against the chemical composition of the mixtures, according to one or more embodiments.

[0090] FIG. 12E shows ^{1}H NMR characterization of a mixture of lidocaine·HCl and caffeine, and the fractions after separation using MagLev, according to one or more embodiments.

[0091] FIG. 12F shows FTIR-ATR characterization of the samples purified in FIG. 12E, according to one or more embodiments.

[0092] FIG. 12G shows unprocessed images of FIG. 12B, according to one or more embodiments.

[0093] FIG. 13 shows time-lapse photography of individual drugs levitating in a MagLev device, according to one or more embodiments.

[0094] FIG. 14 shows separations of powdered mixtures of adulterants and diluents using MagLev, according to one or more embodiments.

[0095] FIG. 15 shows image processing for determination of light intensity of image at different heights (n-direction) in the cuvette, according to one or more embodiments.

[0096] FIG. 16 shows equilibration of equal amounts of lidocaine and caffeine in the MagLev device over time, according to one or more embodiments.

[0097] FIG. 17 shows experimental data, and the normal distribution fitted to this data, for lidocaine, according to one or more embodiments.

[0098] FIG. 18 shows images of the powdered mixtures of lidocaine·HCl and caffeine, in different proportions, after separation in the MagLev device, according to one or more embodiments.

[0099] FIG. 19A shows use of ImageJ to follow the separation of mixtures of lidocaine·HCl and caffeine in different proportions over time in the MagLev device, according to one or more embodiments.

[0100] FIG. 19B shows that the profiles of FIG. 19A were measured manually with ImageJ in the middle of the cuvette, according to one or more embodiments.

[0101] FIG. 20 shows use of ImageJ to measure the separation of mixtures of lidocaine·HCl and caffeine in different proportions in the MagLev device, according to one or more embodiments.

[0102] FIG. 21 shows images of levitated samples of powder in the MagLev device, according to one or more embodiments.

[0103] FIG. 22 shows a box with controlled cuvette illumination for imaging of samples separated in the MagLev device, according to one or more embodiments.

[0104] FIG. 23 shows the classifier for a sample containing 100 wt% lidocaine·HCl, according to one or more embodiments.

[0105] FIG. 24 shows the classifier for a sample containing 100 wt% lidocaine·HCl, according to one or more embodiments.

[0106] FIG. 25 shows the classifier for a sample that contains 50 wt% lidocaine·HCl and 50 wt% caffeine, according to one or more embodiments.

DETAILED DESCRIPTION OF THE INVENTION

[0107] Density can be useful to separate and characterize a wide range of materials. For example, a mixture of particles can be separated and identified based on their behavior in a uniform force gradient (*e.g.*, viscous medium, centrifugal force, magnetic fields, and a combination thereof), which, in turn, is dependent upon their individual densities. Density can also be useful to separate, characterize, and identify both biological and non-biological materials. Density-based methods can be used to, for example, characterize materials, to separate, isolate, or fractionate sub-populations from complex mixtures, and to follow

changes in density in systems (*e.g.*, responses of biological cells to drug treatments, such as bacteria, and chemical reactions, such as polymerization).

[0108] Analytical methodologies—including simple centrifugation-based methods (*e.g.*, Percoll gradient centrifugation) and more specialized techniques and types of instrumentation (*e.g.*, methods based on pycnometers, density gradient columns, or vibrating tube densitometers)—are examples of the uses of density for analysis and separation. More complex approaches (*e.g.*, microfluidics-based approaches using cantilever-based microresonators) are also expanding the uses of density.

[0109] Another technique that enables analysis and separation based on density is magneto-Archimedes levitation (also referred to as "magnetic levitation" or "MagLev"). Existing MagLev uses competing gravitational (buoyant) and magnetic forces to form an effectively continuous density gradient in an aqueous paramagnetic medium in a magnetic field. In some embodiments, a mixture of substances suspended, but not dissolved in, the aqueous paramagnetic medium separates into its component parts based on their densities in response to this gradient. In these embodiments, the existing configuration of MagLev—use of an aqueous paramagnetic medium—presents a challenge to separating or analyzing mixtures of substances in which one or more of its components are aqueous-soluble. Such mixtures include, but are not limited to, recreational drug compositions, pharmaceutical compositions, environmental samples, compositions from chemical manufacturers, compositions from manufacturers of polymers, and composition of food products or ingredients. To overcome this challenge, the inventors found that use of non-aqueous paramagnetic media including a paramagnetic metal complex soluble therein enables MagLev analysis of mixtures including aqueous-soluble substances.

MagLev System

[0110] The present invention is now described with reference to FIG. 1A. In some embodiments, a magnetic levitation system 100 is described, including: a first and second magnets (102a and 102b) having surfaces of their like poles 103a and 103b facing each other. A container 104 is disposed between the first and second magnets' (102a and 102b) like poles (103a and 103b) and contains a solution 106 including a paramagnetic complex in a non-aqueous solvent.

[0111] In some embodiments, the magnetic levitation system is described by reference to FIG. 2A. In these embodiments, the magnetic levitation system consists of a top magnet 200a and a bottom magnet 200b with their like poles, 202a and 202b, respectively, facing each other. A container 204 as described herein contains a paramagnetic gadolinium

complex as described herein, a solvent as described herein, and a sample as described herein. In some embodiments, the container is a cuvette. In some embodiments, a ruler 206 is used to measure the height of one or more components of the sample in the cuvette. In some embodiments, molds 208 are used to hold the magnets 202a and 202b. In some embodiments, fasteners 210 are used to hold the magnets 202a and 202b, container 204, ruler 206, and molds 208 together.

[0112] In some embodiments, the magnetic levitation system is described in FIG. 22, and further includes a camera and a light source for illumination of the container (cuvette).

[0113] In some embodiments, the container is any closed or open vessel, and constructed of any material that is capable of holding the paramagnetic medium. Non-limiting examples of materials include glass, plastic, and a non-magnetic/non-paramagnetic metal. Non-limiting examples of the container include cuvettes, jars, test tubes, centrifuge tubes, and capillary tubes.

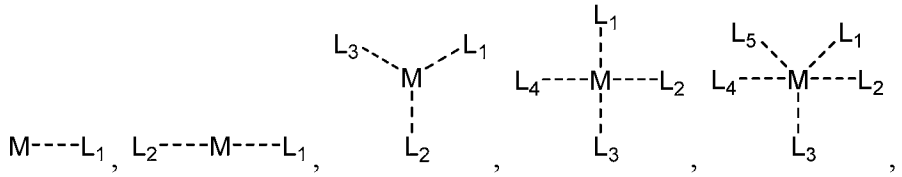
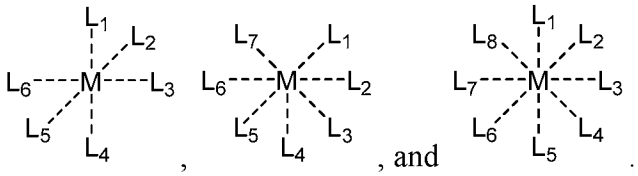
[0114] In some embodiments, the first and/or second magnets are permanent magnets. In some embodiments, the first and/or second magnets are neodymium ("NdFeB") magnets. In some embodiments, the first and/or second magnets are samarium–cobalt ("SmCo") magnets. In some embodiments, the first and/or second magnets are ferrite magnets consisting of iron(III) oxide blended with one or more additional elements, such as barium, manganese, nickel, and zinc. In some embodiments, the first and/or second magnets are Alnico magnets consisting of aluminum, nickel, and cobalt alloys. In some embodiments, the first and/or second magnets are electromagnets. In some embodiments, the first and/or second magnets are superconductive electromagnets.

[0115] In some embodiments, the first and/or second magnets are shaped as blocks, cylinders, spheres, discs, rings, or other geometrical shapes.

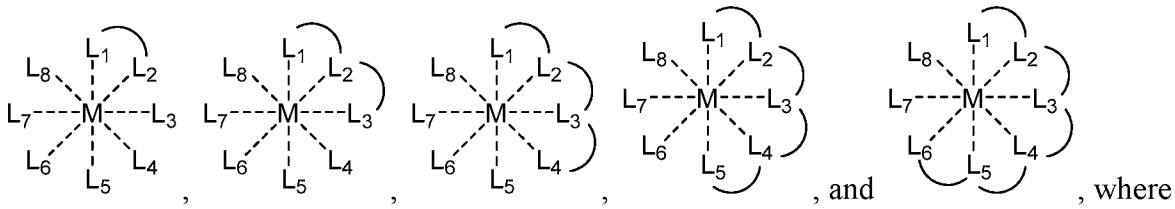
MagLev System in Non-Aqueous Solutions

[0116] In certain embodiments, MagLev analysis of mixtures including aqueous-soluble substances are suspended in non-aqueous solution that include certain complexes.

[0117] In some embodiments, the complex has the structure $M(---L)_x$, where M is a paramagnetic metal, each L is independently a same or different ligand that coordinates to the metal via electron donation, and x is an integer from 1-8. In some embodiments, the complex

has the structure  ,  , and .

In addition to the above complexes, any other combination of L_1-L_8 are contemplated.

[0118] In some embodiments, certain of L_1-L_8 may be joined together by covalent bonding to a substituent group consisting of 1-20 carbon atoms, forming one or more multi-dentate ligands. Non-limiting examples of complexes with multi-dentate ligands include  , where the complex has a bi-dentate L_1-L_2 ligand, a tri-dentate L_1-L_3 ligand, a tetra-dentate L_1-L_4 ligand, a penta-dentate L_1-L_5 ligand, and a hexa-dentate L_1-L_6 ligand, respectively. The symbol "" denotes the substituent group consisting of 1-20 carbon atoms. In addition to the structures shown above, any combination of mono- and multi-dentate ligands is contemplated.

[0119] Non-limiting examples of M include scandium, titanium, vanadium, chromium, manganese, iron, cobalt, nickel, cerium, praseodymium, neodymium, europium, gadolinium, terbium, dysprosium, copper, holmium, erbium, thulium, and lanthanum.

[0120] In some embodiments, at least one of L_1-L_8 includes electron-donating elements, electron-donating groups including said electron-donating elements, or combinations thereof. Non-limiting examples of electron-donating elements include oxygen, nitrogen, sulfur, and the like. Non-limiting examples of electron-donating groups include oxazoles, imidazoles, phosphine oxides (*e.g.*, trioctylphosphine oxide, tributylphosphine oxide, and triphenylphosphine oxide), pyridines, bipyridines, phenanthrolines, diketones, diketonates, diamines, carboxylates (*e.g.*, 2-methylvalerate and ethylenediaminetetraacetic acid), and the like.

[0121] In some embodiments, MagLev is used to separate one or more components of a mixture based on density. In certain embodiments, MagLev is used to separate one or more

components of a mixture that is dissolvable in an aqueous solvent based on density. In some embodiments, the mixture can be suspended in a non-aqueous paramagnetic medium. In these embodiments, when this mixture is placed in a non-aqueous paramagnetic solution between two or more magnets with their like-poles facing each other, the components of the mixture will occupy different positions in the paramagnetic solution according to their density. In some embodiments, by comparing the levitation height of a particular substance in a particular paramagnetic solution to, for example, a table or database of levitation heights of substances in that paramagnetic solution, the identity of the substance can be determined. In other embodiments, alternatively or additionally, the separated components can be isolated from the paramagnetic solution and subjected to further analysis.

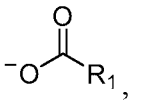
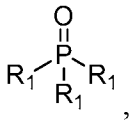
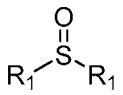
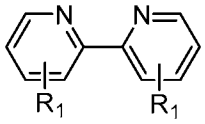
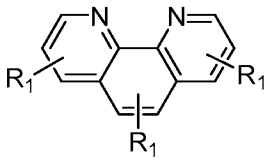
[0122] In other embodiments, MagLev, unlike some of the methods discussed above, is, for example, applicable to a wide range of samples, is highly portable, is relatively inexpensive, and provides relatively fast separation. Therefore, MagLev may be useful for analysis of samples in a wide range of settings. Non-limiting examples of such settings can include academic and industrial research, development, and manufacturing, including in the pharmaceutical and materials science fields, environmental testing, such as testing for pollutants and other contaminants, and law enforcement, such as forensic analysis. In some embodiments, MagLev can be used for forensic analysis of powdered mixtures of illicit drugs, adulterants, and/or diluents. In some embodiments, the separated substances are also readily retrievable from the paramagnetic medium by, for example, pipet, which highlights the added advantage of MagLev for both separation and analysis of mixtures.

[0123] In some embodiments, the exemplary advantages of MagLev make it an attractive means for analyzing mixtures of illicit drugs by, for example, forensic analysts in field settings. Small (*e.g.*, < 50 mg) samples of mixtures can be challenging to separate or characterize (*e.g.*, determine the identities of the components thereof) because of the relatively low concentration or weight percent of the components of the mixture. Large mixtures (*e.g.*, > 50 mg), too, can be challenging to separate or characterize where one or more components of the mixture are present in low concentration or weight percent (*e.g.*, < 10 wt%). Therefore, in some embodiments, MagLev can be particularly useful for separation and identification of the components present in a complex mixture at dilute concentrations or low weight percent, including, but not limited to, small samples of illicit drugs that are diluted by adulterants and other dilutants.

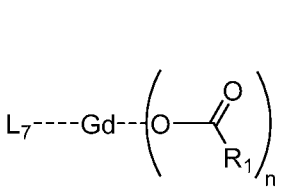
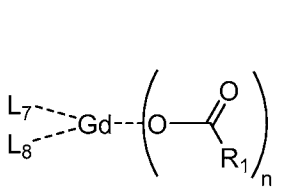
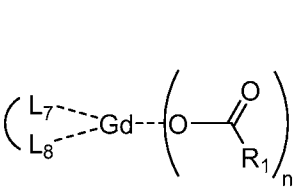
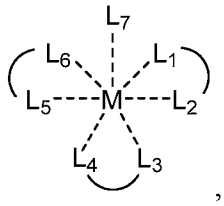
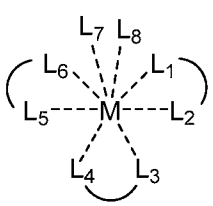
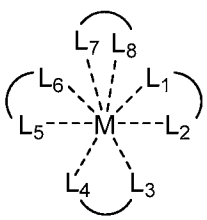
[0124] In some embodiments, identifying illicit drugs are challenging because existing conventional paramagnetic solutions useful for MagLev are aqueous, and most illicit drugs

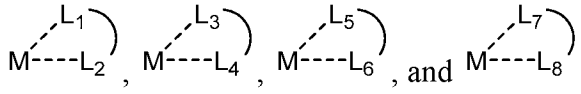
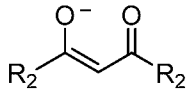
are water-soluble. Moreover, existing conventional paramagnetic complexes useful for MagLev are not soluble in non-aqueous solvents. Applicants have surprisingly found that these challenges can be overcome by using certain paramagnetic complexes that are soluble in non-aqueous solvents. In some embodiments, the paramagnetic complex includes a scandium, titanium, vanadium, chromium, manganese, iron, cobalt, nickel, cerium, praseodymium, neodymium, europium, gadolinium, terbium, dysprosium, copper, holmium, erbium, thulium, or lanthanum complexe, each including at least one phosphine oxide, carboxylate, or diketonate ligand. In some embodiments, the paramagnetic complex includes a gadolinium complex including at least one phosphine oxide, carboxylate, or diketonate ligand, each containing electron-donating elements (*e.g.*, oxygen and nitrogen) or groups (*e.g.*, oxazoles, imidazoles, phosphine oxides, pyridines, bipyridines, and phenanthrolines.

Certain Paramagnetic Complexes

[0125] In certain embodiments, at least one of L_1-L_8 includes  ,  ,  ,  , or  , where each occurrence R_1 is independently H, (C_1-C_{20})alkyl, (C_2-C_{20})alkenyl, (C_2-C_{20})alkynyl, (C_3-C_{10})cycloalkyl, (C_6-C_{10})aryl, or (C_6-C_{10})heteroaryl, each of which is optionally substituted with one or more substituents selected from the group consisting of halogen, R^a, OR^a, NR^aR^b, COR^a, CO_2R^a, or $CONR^aR^b$; and where R^a and R^b are independently selected from the group consisting of hydrogen and (C_1-C_6)alkyl.

[0126] In some embodiments, the paramagnetic complex has the structure

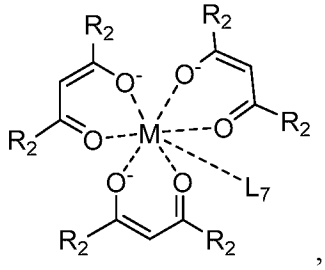
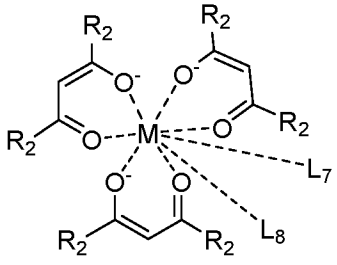
 ,  ,  ,  ,  , or  , where n is an integer from 1-7 and where "⌒" denotes the group consisting of 1-20 carbon atoms.

[0127] In some embodiments,  , and  , where each occurrence of R_2 is independently H, (C_1-C_{20})alkyl, (C_2-C_{20})alkenyl, (C_2-C_{20})alkynyl, (C_3-C_{10})cycloalkyl, (C_6-C_{10})aryl, or (C_6-C_{10})heteroaryl, each of which is optionally substituted with one or more substituents selected from the group consisting of halogen, R^a, OR^a, NR^aR^b, COR^a, CO_2R^a, or $CONR^aR^b$; and where R^a and R^b are independently selected from the group consisting of hydrogen and (C_1-C_6)alkyl.

[0128] As described herein, non-limiting examples of alkyl groups include methyl, ethyl, propyl, isopropyl, n-butyl, t-butyl, isobutyl pentyl, hexyl, isohexyl, heptyl, 4,4-dimethylpentyl, octyl, 2,2,4-trimethylpentyl, nonyl, decyl, undecyl, dodecyl, and the like. Non-limiting examples of alkenyl groups include ethenyl, allyl, propenyl, 2-propenyl, (*E*)-but-2-enyl, (*Z*)-but-2-enyl, 2-methy(*E*)-but-2-enyl, 2-methy(*Z*)-but-2-enyl, 2,3-dimethy-but-2-enyl, (*Z*)-pent-2-enyl, (*E*)-pent-1-enyl, (*Z*)-hex-1-enyl, (*E*)-pent-2-enyl, (*Z*)-hex-2-enyl, (*E*)-hex-2-enyl, (*Z*)-hex-1-enyl, (*E*)-hex-1-enyl, (*Z*)-hex-3-enyl, (*E*)-hex-3-enyl, and (*E*)-hex-1,3-dienyl. Non-limiting examples of alkynyl groups include ethynyl, prop-1-ynyl, prop-2-ynyl, but-1-ynyl, but-2-ynyl, pent-1-ynyl, pent-2-ynyl, hex-1-ynyl, hex-2-ynyl, and hex-3-ynyl. Non-limiting examples of cycloalkyl groups include cyclopropyl, cyclobutyl, cyclopentyl, cyclohexyl, and cycloheptyl.

[0129] Non-limiting examples of aryls include phenyl, biphenyl and naphthyl. Non-limiting examples of heteroaryls include pyridinyl, pyridazinyl, pyrimidyl, pyrazyl, triazinyl, pyrrolyl, pyrazolyl, imidazolyl, (1,2,3,)- and (1,2,4)-triazolyl, pyrazinyl, pyrimidinyl, tetrazolyl, furyl, thienyl, isoxazolyl, thiazolyl, isoxazolyl, oxazolyl, quinolinyl, isoquinolinyl, indolyl, benzothiazolyl, benzoxazolyl, benzoxadiazolyl, benzothienyl, benzimidazolyl, benzofuryl, and the like.

[0130] In some embodiments, the paramagnetic complex has the structure,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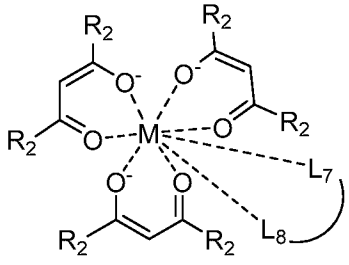
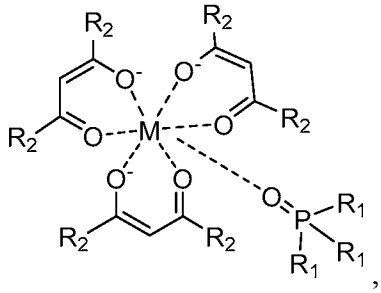

, where R_2 is defined as above.

[0131] In some embodiments, the paramagnetic complex has the structure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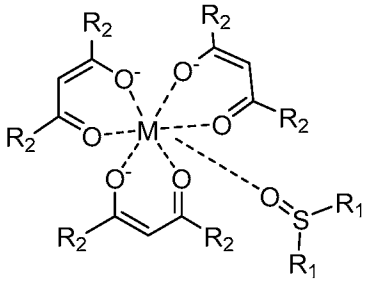
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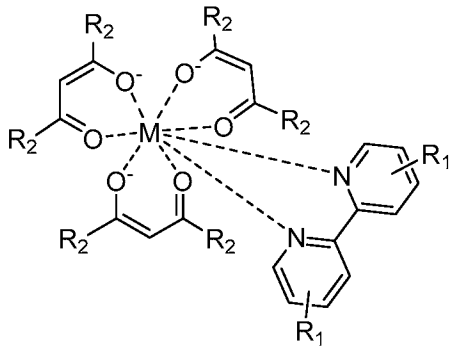
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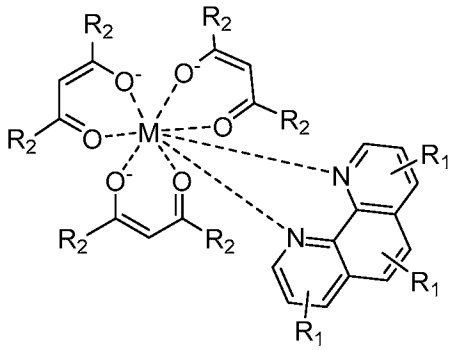
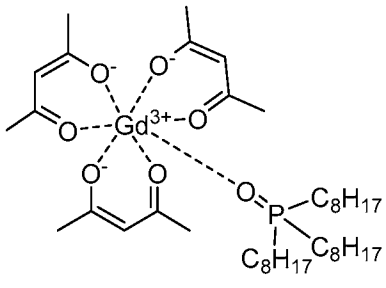
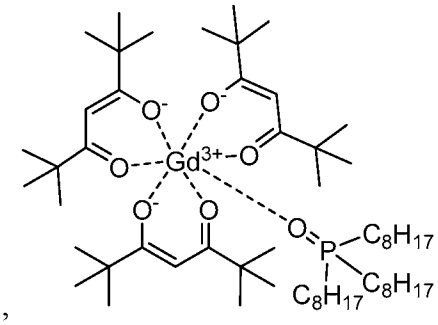

, where R_1 and R_2 are defined as above.

[0132] In some embodiments, each occurrence of R_1 and R_2 is independently (C_1-C_{10})alkyl or (C_6-C_{10})aryl. In some embodiments, each occurrence of R_1 and R_2 is independently methyl, ethyl, propyl, butyl, pentyl, hexyl, heptyl, octyl, nonyl, decyl, phenyl, or isomers thereof. In some embodiments, each occurrence of R_1 and R_2 is independently methyl, butyl, tert-butyl, octyl, or phenyl.

[0133] In some embodiments, M is gadolinium.



[0134] In some embodiments, the paramagnetic complex is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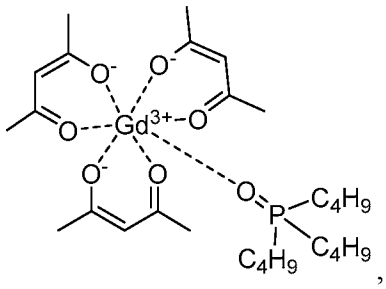
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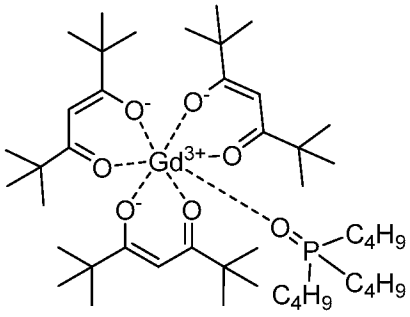
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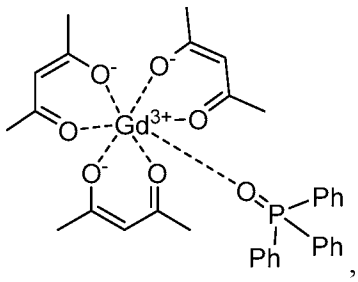
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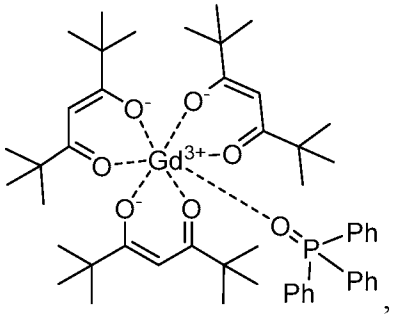
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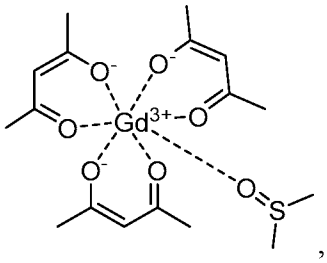
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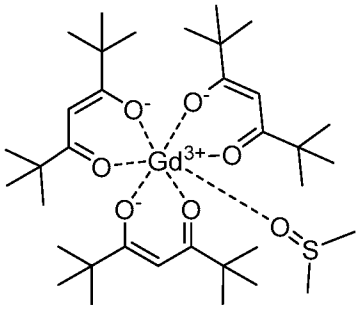
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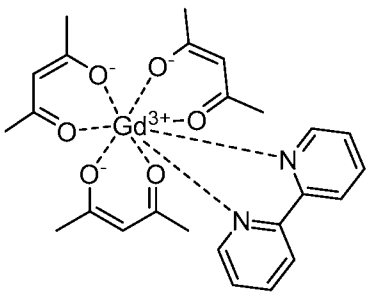
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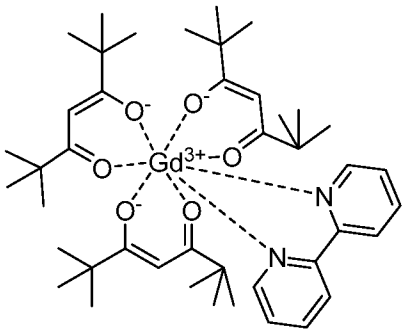

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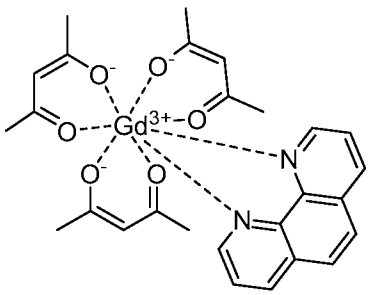

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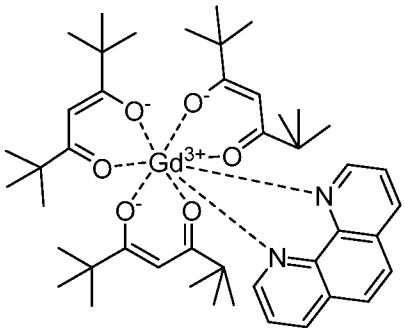

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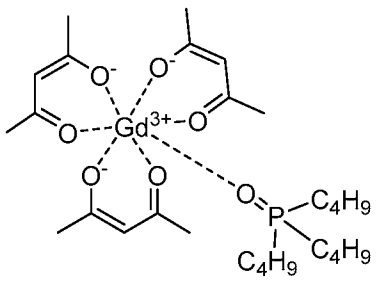
[0135] In some embodiments, the paramagnetic complex is



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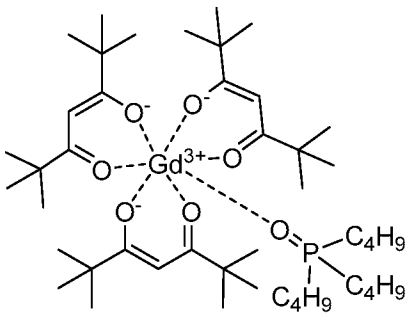


.

[0136] In some embodiments, the solvent is a non-aqueous solvent. Non-limiting examples of non-aqueous solvents include acyclic and cyclic hydrocarbons, acyclic and cyclic halo- or per-halo hydrocarbons, aromatic hydrocarbons, acyclic and cyclic ethers, and acyclic and cyclic aldehydes, ketones, esters, and amides. In some embodiments, the solvent is pentane, hexane, heptane, octane, nonane, decane, undecane, dodecane, carbon tetrachloride, tetrachloroethylene, dichloromethane, trichloromethane, ethers (*e.g.*, diethyl ether and tetrahydrofuran), and esters (*e.g.*, ethyl acetate, and butyl acetate), including all isomers and a combinations thereof. In some embodiments, the solvent is hexane,

tetrachloroethylene, or a combination thereof. In some embodiments, the solvent is tetrachloroethylene.

[0137] In some embodiments, the solvent is an aqueous or protic solvent. Non-limiting examples of aqueous or protic solvents include water, acyclic and cyclic alcohols, amines, thiols, carbonates, sulfoxides, and carboxylic acids.

Analytical Methods Using Position Analysis

[0138] In another aspect, a method of analyzing a sample including one or more solid compounds is described, including:

(a) providing the magnetic levitation system of any one of the preceding embodiments;

(b) depositing the sample in the solution including the paramagnetic gadolinium complex; and

(c) allowing each of the solid compounds in the sample to migrate to a position in the container indicative of its density.

[0139] In some embodiments, the sample can be an amorphous, crystalline, or powdered sample. In some embodiments, the sample includes controlled substances, adulterants, and diluents that are found in pharmaceuticals and recreational drug products.

[0140] In some embodiments, the one or more solid compounds are present in the sample 108 at between 0.01 and 100 weight percent. In some embodiments, the one or more solid compounds are present in the sample at 0.01, 0.05, 0.1, 0.5, 1, 5, 10, 15, 20, 30, 40, 50, 60, 70, 80, 90, or 100 weight percent, or within a range of the weight percentage bounded by any two values described herein. In some embodiments, the one or more compounds are present in the sample between 0.01 and 10 weight percent.

[0141] Non-limiting examples of the one or more solid compounds in the sample are fentanyl, acetyl fentanyl, benzyl fentanyl, carfentanyl, cocaine, heroin, oxycodone, methamphetamine, cannabinoids, lysergic acid diethylamide, methaqualone, methadone, hydromorphone, Ritalin, Adderall, peyote, 3,4-methylenedioxymethamphetamine, acetaminophen, caffeine, diltiazem, dipyrone/metamizole, lidocaine, hydroxyzine, levamisole, papaverine, procaine, phenacetin, dimethyl sulfone, D-fructose, D-glucose, α-lactose, D-mannitol, sodium carbonate, starch, including potato starch, sucrose, talc, quinine, butylated hydroxytoluene, hypromellose, polyethylene glycol, polyethylene oxide, magnesium stearate, titanium dioxide and other colorants, and isomers and mixtures thereof. In some embodiments, the one or more solid compounds present in the sample include

fentanyl·HCl and/or caffeine. In some embodiments, the one or more solid compounds, including those listed here, are present in the sample in free-base or salt form. Non-limiting examples of salt forms include sodium, aluminum, potassium, calcium, hydrochloride, citrate, nitrate, sulfate, acetate phosphate, diphosphate, maleate, mesylate, tartrate, and gluconate salts. In some embodiments, the salt is a hydrochloride salt.

[0142] In some embodiments, the method further includes

(d) analyzing one or more of the solid compounds to determine or confirm its identity

[0143] In some embodiments, the method of analyzing a sample including one or more solid compounds optionally includes positioning the sample container such that one or more of the levitated components contacts the wall of the container, followed by analyzing said component(s) through the wall of the container using a portable spectrometer. In some embodiments, the portable spectrometer includes a Raman spectrometer.

[0144] In some embodiments, the method of analyzing a sample including one or more solid compounds optionally includes isolating the one or more solid compounds from the paramagnetic solution after migration. In some embodiments, isolation is conducted by removing the one or more solid compounds using, for example, a pipette, a siphon, a spoon, a spatula, or a small basket.

[0145] In some embodiments, the one or more solid compounds are analyzed by other techniques after isolation from the paramagnetic solution 106. Non-limiting examples of such techniques include infrared spectroscopy, including Fourier transform infrared spectroscopy with attenuated total reflectance ("FTIR-ATR"), mass spectrometry, nuclear magnetic resonance spectroscopy ("NMR"), Raman spectroscopy, X-ray diffractometry, capillary electrophoresis, gas chromatography, ion-mobility spectrometry, liquid chromatography, microcrystalline tests, supercritical fluid chromatography, thin layer chromatography, ultraviolet/visible spectroscopy, macroscopic (visual) examination, colorimetric tests, fluorescence spectroscopy, immunoassays, melting point analysis, and pharmaceutical identifiers (package inserts). In some embodiments, the technique is FTIR-ATR. In some embodiments, the technique is Raman spectroscopy. In some embodiments the technique is mass spectrometry. In some embodiments, the technique is X-ray diffractometry. In some embodiments, the technique is a colorimetric test. In some embodiments, the technique uses a portable or handheld device.

[0146] In some embodiments, the method of analyzing a sample including one or more solid compounds further includes:

(e) generating a profile of the position of the one or more compounds relative to the container; and

(f) generating a database including a plurality of profiles, each of which corresponds to a known solid compound or a known mixture of solid compounds.

[0147] In some embodiments, the profile of the sample and the profiles of the database are determined at a plurality of time points after the sample is deposited in the solution in step (b).

[0148] In some embodiments, the MagLev device is described by FIG. 22. In these embodiments, the Maglev device includes a box, a light source for controlled illumination of the container, and a camera for imaging sample separation in the MagLev device at different time points.

[0149] In some embodiments, the method of analyzing a sample including one or more solid compounds further includes:

(g) comparing the generated profile of the sample to the profiles in the database.

[0150] In some embodiments, step (g) further includes determining the particle size or the mixture of particle sizes of the one or more solid compounds.

[0151] In some embodiments, the step of comparing the generated profile of the sample to the profiles in the database includes determining and/or confirming the identity of the one or more solid compounds, or determining and/or confirming the source of the one or more solid compounds, or determining and/or confirming the particle size or the mixture of particle sizes of the one or more compounds, based on the comparison.

[0152] In some embodiments, the step of comparing the profile of the sample to the profiles in the database further includes using a computer to calculate the distances between the generated profile of the sample and the profiles in the database to identify a profile in the database within a minimum distance to the generated profile. Non-limiting examples of the distance are the Mahalanobis or Euclidian distances.

[0153] In some embodiments, dynamic time warping ("DTW") is used to measure the similarity between profiles of the sample generated at a plurality of time points. In some embodiments, DTW is used to measure the similarity between profiles of the sample generated at a plurality of time points to profiles in the database generated at a plurality of time points. In some embodiments, the profiles of the sample and the profiles in the database are averaged and DTW used to measure the similarity between the average profile of the sample and the average profiles in the database.

[0154] In some embodiments, the profile consists of an image of the container. In some embodiments, DTW is used to compare the generated image of the container to images in the database. In some embodiments, images are recorded at a plurality of time points, optionally averaged, and DTW used to compare the generated images/average image to images/average images in the database. In some embodiments, the light intensity as a function of position in the container is measured to determine the profile. In these embodiments, the light intensity at a position of the container including only paramagnetic solution is different than the light intensity at a position of the container where one or more compounds is present. In some embodiments, DTW is used to compare the generated light intensity profile with the light intensity profiles in the database. In some embodiments, light intensity profiles are generated at a plurality of time points, optionally averaged, and DTW used to compare the generated light intensity profiles/average profile to the generated light intensity profiles/average profiles in the database.

[0155] In some embodiments, DTW finds point correspondences between generated and database profiles by warping them in the time domain. In some embodiments, DTW computes the set of point correspondences that minimizes the cumulative distance between the sequences.

[0156] In some embodiments, the averaging process is non-trivial when performed on variable-length signals. Therefore, in some embodiments, DTW barycenter averaging ("DBA") was used to compute the average profile, including profiles consisting of images and light intensities, and the standard deviation. For example, FIGS. 23-25 show the measured light intensity for 50 mg powder samples containing 100 wt% lidocaine HCl, 50-50 wt% lidocaine HCl and caffeine, and 100 wt% caffeine as a function of the height of the "cloud" of that sample levitating in a MagLev device, according to some embodiments. This data was used to calculate, using DBA, a "classifier" curve for lidocaine (FIG. 23), caffeine (FIG. 24), and a 50/50 (wt%) lidocaine-caffeine mixture (FIG. 25), according to some embodiments. Error bars in the classifier plots correspond to the standard deviations after averaging ten different separations, according to some embodiments. In some embodiments, unknown mixtures can be compared to the class representation, including by calculating their Mahalanobis distances.

Classifying unknown powdered mixtures

[0157] In some embodiments, an unknown mixed powder sample can be analyzed by calculating the similarity between the profile, optionally averaged over a plurality of time points, (*i.e.*, position of the one or more compounds relative to the container) of an unknown

sample and the profiles, optionally averaged over a plurality of time points, of known compounds or mixtures in the database. In some embodiments, the closest similarity between the unknown profile and a known profile in the database is used to identify the unknown mixture. As used herein, the similarity between the unknown profile and each known profile refers to the distance (*e.g.*, Mahalanobis distance) as described above.

[0158] In some embodiments, if the similarity measurement does not reach a minimum distance, the event will be labelled as unknown. In some embodiments, the minimum distance (*e.g.*, Mahalanobis distance), is a few (*e.g.*, 10 s) standard deviations. Otherwise, in other embodiments, the unknown will be identified according to the greatest similarity.

[0159] In some embodiments, mixtures are detected that were previously identified and possess a database profile. In some embodiments, combinations of substances, such as, for example, lidocaine and caffeine, represent new representations. In some embodiments, this method may be especially useful for identification of samples that come from the same batch as a sample that has previously been classified, and to find samples that are of the same composition (*i.e.*, same recipe), but not necessarily the same batch.

[0160] In some embodiments, the comparison between generated profiles and profiles in the database uses machine learning. In some embodiments, the machine learning includes deep neural networks, such as, for example, convolutional neural networks. In some embodiments, supervised deep learning, a subset of methods within machine learning, is used to identify known constellations of mixtures. In these embodiments, the convolutional neural network ("CNN") is trained on hundreds-to-thousands of parameters, from datasets of labeled data (various mixtures of drugs) using cloud services, such as IBM Watson, since, in some embodiments, training of such networks can be computationally involved. In some embodiments, the analysis of unknown mixtures consists of inserting a new image into the trained neural network which will output the maximum-likelihood class. The CNN can be extended with any number of known mixtures; this approach requires, in some embodiments, large numbers of labeled data (*e.g.*, images from mixtures of drugs in MagLev).

[0161] In yet another aspect, a kit is described, including:

a first and second magnets as described in any one of the previous embodiments;

a container as described in any one of the previous embodiments;

a paramagnetic gadolinium complex as described in any one of the previous embodiments, including at least one phosphine oxide ligand; and

instructions for assembling a magnetic levitation system as described in any one of the previous embodiments. In some embodiments, the kit further includes the solvent as

described in any one of the previous embodiments. In some embodiments, the instructions for assembling a magnetic levitation system include placing the first and second magnets such that the surfaces of their like-poles are facing each other. In some embodiments, the instructions for assembling a magnetic levitation system further include placing a container the first and second magnets' like poles. In some embodiments, the instructions for assembling a magnetic levitation system further include adding, to the container, a solution including the paramagnetic gadolinium complex in the solvent as described in any of the embodiments disclosed herein. In some embodiments, the instructions for assembling a magnetic levitation system further include depositing a sample including one or more solid compounds in the solution including the paramagnetic gadolinium complex; and allowing each of the solid compounds in the sample to migrate to a position in the container indicative of its density.

EXAMPLES

Example 1: MagLev Theory

[0162] In some embodiments, a diamagnetic object (*e.g.*, a crystal or a particle from a mixture of powdered drugs) achieves a stable levitation height in a paramagnetic solution in an applied magnetic field (*e.g.*, a linear field gradient) when the magnetic force, $\vec{F}_{mag}$, the object experiences (as a result of the interaction between the paramagnetic suspending solution and the applied magnetic field) counterbalances its gravitational force, $\vec{F}_g$, (corrected for the effect of buoyancy; *see* FIG. 1A). In some embodiments, Equation 1 gives the levitation height, h (m), of the centroid (volumetric center) of the sample with respect to the surface of the bottom magnet.

$$h = \frac{(\rho - \rho_{medium})g\mu_o d^2}{(\chi - \chi_{medium})4B_o^2} + \frac{d}{2} \qquad \text{(Equation 1)}$$

In some embodiments, ρ (g cm^{-3}) is the density of the sample, ρ_{medium} (g cm^{-3}) is the density of the paramagnetic solution, χ (unitless) is the magnetic susceptibility of the sample, χ_{medium} (unitless) is the magnetic susceptibility of the paramagnetic solution, g (9.8 m s^{-2}) is the constant of gravitational acceleration, μ_o ($4\pi \times 10^{-7}$ N•A^{-2}) is the magnetic permeability of the free space, B_o (T) is the strength of the magnetic field at the center of the top surface of the bottom magnets, and d (m) is the distance of separation between the two like-poles-facing magnets.

[0163] FIG. 1A shows a schematic diagram of the relevant forces during MagLev of powdered mixtures of illicit drugs, according to some embodiments. FIG. 1B shows the

magnetic field, B, between the magnets (distance of separation 25 mm) of the MagLev device simulated using COMSOL Multiphysics, according to some embodiments. The plot shows the strength of the magnetic field and the white arrows indicate the strength and direction (from N to S) of the magnetic field at the locations of the arrows, according to some embodiments. FIG. 1C shows the magnetic force—plotted as the logarithm of the magnitude of the force, $\propto log|F_{mag}| = log|\frac{(\chi_{sample}-\chi_{medium})}{\mu_0}V(\vec{B}\cdot\nabla)\vec{B}|$—a sample particle (modeled using a cubic crystal having a side of 100 μm) experiences when suspended in a paramagnetic solution (0.5 M $Gd(DPM)_3TOPO$) and placed in the magnetic field shown in FIG. 1B, according to some embodiments. The white arrows indicate the strength and direction of the magnetic force acting on the sample at the locations of the arrows, according to some embodiments. In some embodiments, the magnetic force the sample experiences is the result of the attractive interaction of the applied magnetic field and the paramagnetic solution in which the diamagnetic sample is suspended. In comparison, in some embodiments, the repulsive interaction between the magnetic field and the diamagnetic sample is orders of magnitude smaller, and, thus, can be neglected.

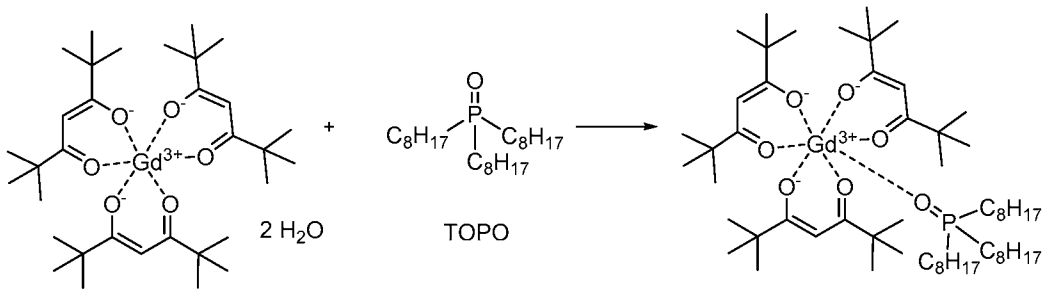
Example 2: Construction of the MagLev Device

[0164] The MagLev device dimensions and weight were 205 × 45 × 45 mm and 700 g, respectively). The MagLev device consisted of two NdFeB magnets (Neodymium Magnets N42 Block; dimensions: 25.4 × 25.4 × 50.8 mm; appliedmagnets.com), with like-poles facing each other, with a 25.5 mm face-to-face separation resulting in a 0.51 T magnetic field (as measured with a DC gauss-meter; model GM1-ST; AlphaLab, Inc.) at the surface of the magnets (*see* Figure 2A). The magnets were mechanically secured in a stand made from (i) acrylonitrile-butadiene-styrene-plastic ("ABS" plastic) parts that were designed with computer-aided design (Solidworks™) and printed with a 3D printer (Stratasys Fortus 250mc); (ii) four super-corrosion-resistant 316 stainless steel rods (8" long, 1/4"-20 thread size, McMaster-Carr); (iii) 16 stainless steel hex nuts (1/4"-20 thread size, McMaster-Carr), and (iv) 8 stainless steel cap nuts (1/4"-20 thread size, McMaster-Carr). In some embodiments, the position of the hex nuts along the rods can be adjusted to change the distance between the magnets. In some embodiments, the metal parts interact weakly with the magnets, and, therefore, cause minimal disturbances to the magnetic field between the two like-poles.

[0165] FIG. 2A shows that the Maglev device consisted of two magnets (dashed rectangles) with like-poles facing each other, according to some embodiments. The magnets

were mechanically secured using plastic parts, and steel rods, and nuts. The glass beads levitated in a paramagnetic solution. The axis of the magnetic centerline is illustrated by the black dotted line (parallel to the z-direction) between the two magnets, according to some embodiments. FIG. 2B shows a custom-made plastic cuvette filled with paramagnetic solution sitting in the MagLev device, according to some embodiments. The shape of the cuvette allowed access with a Pasteur pipette from the side of the magnet to extract the separated compounds. A 50 mg mixture consisting of 95 wt% lidocaine·HCl and 5 wt% caffeine after 30 minutes of separation is shown in the cuvette, according to some embodiments. The paramagnetic solution in FIG. 2A and FIG. 2B contained $Gd(DPM)_3TOPO$ (450 mM) dissolved in a mixture of 23 vol% hexane and 77 vol% tetrachloroethylene. The face-to-face separation between the magnets was 25 mm. The images were uniformly post-processed for contrast and clarity.

Example 3: Synthesis of the $Gd(DPM)_3TOPO$-Chelate Complex



[0166] Tris(dipivaloylmethanato) gadolinium(III) ($Gd(DPM)_3$; 2.0 g, 2.7 mmol; Alfa Aesar) was suspended in hexanes or *n*-heptane (20 mL; 10 mL per g of starting material) at room temperature. Trioctylphosphine oxide (TOPO; 1.0 g, 2.7 mmol; Sigma-Aldrich) was added to form a colorless suspension, which became a clear solution within 10-30 minutes (depending on batch size). The solution was stirred at room temperature (22 °C) for approximately 18 hours. The solvent was removed on a rotary evaporator (60 °C bath temperature) at reduced pressure (first at 100-25 mbar, then at 10-3 mbar) to obtain the $Gd(DPM)_3TOPO$ complex as a pale yellow, viscous oil (2.88 g, 2.67 mmol) with a density of approximately 1.1 g/cm^3. This synthesis was successfully performed starting with 1-30 g of $Gd(DPM)_3$. The yellow color intensified with larger scales and higher concentrations. The compound was characterized with Fourier transform infrared attenuated total reflectance ("FTIR-ATR") spectroscopy (*see* FIG. 3).

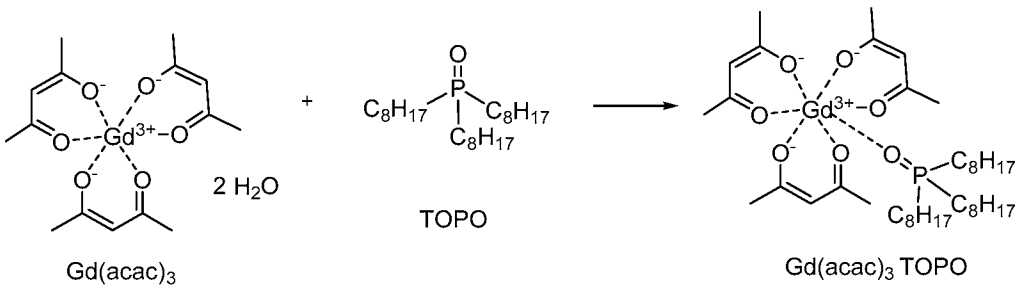
[0167] FIG. 3 shows FTIR-ATR spectra of $Gd(DPM)_3TOPO$ and $Gd(acac)_3TOPO$ (synthesis described in Example 4), according to some embodiments. The solvent

tetrachloroethylene was present for the $Gd(acac)_3TOPO$ compound. IR-ATR ($Gd(DPM)_3TOPO$): 2924 cm^{-1} (C-H stretch, m), 1573 cm^{-1} (C=C and C=O tautomeric stretch, vs) 1137 cm^{-1} (P=O stretch, s). IR-ATR ($Gd(acac)_3TOPO$ in tetrachloroethylene): 2923 cm^{-1} (C-H stretch, m), 1598 cm^{-1} (C=C and C=O tautomeric stretch, s), 1142 cm^{-1} (P=O stretch, m), 906 cm^{-1} and 776 cm^{-1} (tetrachloroethylene solvent, s).

[0168] FTIR-ATR (Bruker Platinum) spectra of $Gd(DPM)_3TOPO$ (900 mM) and $Gd(acac)_3TOPO$ (1100 mM in tetrachloroethylene) were recorded by placing a drop of chelate on the ATR diamond window (air set as blank). The spectrum of tetrachlorochloroethylene was measured as a control (air set as blank). Spectra were recorded from 4000-400 cm^{-1} at a resolution of 1 cm^{-1} with 64 sample and background scans (*see* FIG. 3). The spectra of the $Gd(DPM)_3TOPO$ and $Gd(acac)_3TOPO$ chelates before and after filtering through activated charcoal showed no significant difference, which suggested that the complexes were relatively pure after synthesis.

[0169] The compound was stable for more than one month at 22 °C in a capped and air-tight bottle when stored at room temperature in ambient air. In some cases, precipitation occurred after extended storage. The precipitate made the $Gd(DPM)_3TOPO$ oil appear opaque and, in some embodiments, can be removed by diluting the compound with hexane to 450 mM and filtering the solution through polyether sulfone syringe filters (0.2 μm, Thermo Fisher Scientific, Inc.).

Example 4: Synthesis of the $Gd(acac)_3TOPO$-Chelate Complex



[0170] Gadolinium(III) acetylacetonate ($Gd(acac)_3$; 2.3 g, 5.0 mmol) was added to a 50 mL round-bottomed flask attached to a vacuum outlet and TOPO (2.0 g, 5.2 mmol) was added as a powder. The temperature of this solid mixture was slowly raised to 100 °C and kept constant for five minutes. The TOPO melted and solubilized the $Gd(acac)_3$. Heating was stopped and a vacuum (150 mbar) was applied for 2 minutes. In some embodiments, heating for longer periods led to significant darkening of the solution and formation of insoluble precipitates (*e.g.*, inorganic polymers). Also, in some embodiments, rapid heating led to overheating, and hence, in these embodiments, the heating step was conducted slowly

(over approximately 5 minutes). This mixture was cooled to 30-40 °C and 1,2-dichloroethylene (4.5 mL) was added. The solution looked turbid. The small amount of insoluble precipitate was removed by filtration using a polysulfone syringe filter (0.4 μm pore size). In some cases, filter paper did not work, as pressure was required to filter the relatively viscous solution. This solution was cooled to room temperature to give a faint yellow solution with a density of approximately 1.3 g/cm^3. Treatment with active charcoal did not lead to significant improvement in the color of the solution. The compound was characterized with FTIR-ATR (*see* FIG. 3).

[0171] Gadolinium(III) diethylenetriamine triacetic acid didecyldiacetamide, C11-DTTA, molecular weight 1107 g mol^{-1}) was also synthesized. This compound is a hexadentate chelate with at least two free coordination sites on gadolinium(III), which may be occupied by water. In the absence of stronger ligands, this complex dissolved in the organic solvents at concentrations up to approximately 0.4 M. However, in some cases, above a concentration of 0.2 M, the increased viscosity of the solutions (higher viscosity than glycerol) impeded the separation of particles, and, in these cases, caused a large increase in the time required for separation with MagLev.

Example 5: Determination of Magnetic Susceptibility for the Paramagnetic Complexes

[0172] The magnetic susceptibilities of the gadolinium chelate complexes were determined using the Evans method. In some embodiments, the magnetic susceptibilities for small molecules can be calculated from experimental data using Equation 2:

$$\chi_c = \frac{3\Delta f}{4\pi F c} \qquad \text{(Equation 2)}$$

where χ_c is the magnetic susceptibility (m^3 mol^{-1}) of the compound, Δf is the observed difference in chemical shift in ^{1}H-NMR (Hz), F the frequency of the NMR spectrometer (Hz), and c is the concentration (mol m^{-3}) of the paramagnetic substance.

Table 1: Calculation of the magnetic susceptibilities of the Gd-chelate complexes using the Evans method (Equation 2). The values were in agreement with previously reported magnetic susceptibilities for gadolinium chelate complexes. The density of the solution was assumed to be the same as the deuterated chloroform solvent because of the low concentration (1.4-1.6 wt%) of the paramagnetic complexes.

Description	Unit	$Gd(DPM)_3TOPO$	$Gd(acac)_3TOPO$	Solvent ($CDCl_3$)
Mass	g	0.0151	0.0124	
Molecular weight	g mol^{-1}	1093.7	841.2	
No. of moles	mol	1.38×10^{-5}	1.47×10^{-5}	
Density	kg m^3	-	-	1500

Description	Unit	$Gd(DPM)_3TOPO$	$Gd(acac)_3TOPO$	Solvent ($CDCl_3$)
Volume	m^3	-	-	0.6×10^{-6}
Concentration (c)	mol m^{-3}	23.0	24.6	
Difference in chemical shift of $CHCl_3$ in ^1H-NMR (Figure S7& S8)	ppm	2.03	1.97	
Difference in chemical shift of $CHCl_3$ in ^1H-NMR (Δf) (conversion from ppm)	Hz	1218	1188	
NMR instrument frequency (F)	Hz	600×10^6	600×10^6	
Temperature	K	298	296	
Magnetic susceptibility (χ_c):	m^3 mol^{-1}	2.10×10^{-8}	1.90×10^{-8}	

[0173] The differences in chemical shifts (Δf) that were caused by the paramagnetic complexes were recorded using ^1H NMR (*see* FIG. 5 and FIG. 6) in a solvent mixture of chloroform (40 μL) and deuterated chloroform (2 mL). Coaxial inserts were made from cylindrical glass capillaries with an inner diameter of 0.8 mm (Corning® 9530-2 PYREX® 100 mm capillary melting point tube) that were filled with the solvent mixture (without any paramagnetic complex) and sealed in both ends using a flame. $Gd(DPM)_3TOPO$ (15.09 mg) and $Gd(acac)_3TOPO$ (12.40 mg) were dissolved separately in 0.6 mL of the solvent mixture and placed in NMR tubes (Thin Wall Precision NMR Sample Tube, Ø 5 mm, 17.8 cm length). The sealed capillary tubes were placed at the bottom of the NMR tubes, and the ^1H NMR spectra (Agilent DD2 600 MHz NMR spectrometer) were recorded using a standard pulse program with 64 scans and 2 seconds relaxation time. The temperature was also recorded.

[0174] FIG. 5 shows the ^1H NMR spectrum of 1.6 wt% $Gd(DPM)_3TOPO$ in deuterated chloroform ($CDCl_3$) containing 2% v/v chloroform ($CHCl_3$), according to some embodiments. A sealed, coaxial insert contained the solvent mixture, but no solute. The magnetic susceptibility of the gadolinium chelate complex was calculated from the difference in chemical shift between the resonances of $CHCl_3$ in the coaxial insert (at 7.26 ppm, labeled '*') and the $CHCl_3$ in the paramagnetic solution (at 5.23 ppm, labeled '**').

[0175] FIG. 6 shows the ^1H NMR spectrum of 1.4 wt% $Gd(acac)_3TOPO$ in deuterated chloroform ($CDCl_3$) containing 2% v/v chloroform ($CHCl_3$), according to some embodiments. A sealed, coaxial insert contained the solvent mixture, but no solute. The magnetic susceptibility of the gadolinium chelate complex was calculated from the difference

in chemical shift between the resonances of $CHCl_3$ in the coaxial insert (at 7.26 ppm, labeled '*') and the $CHCl_3$ in the paramagnetic solution (at 5.29 ppm, labeled '**').

Example 6: Performance of the $Gd(DPM)_3TOPO$ as a Paramagnetic Solution for MagLev Separation

[0176] The $Gd(DPM)_3TOPO$ was obtained from the synthesis shown in Example 3 as a viscous oil, which was fully soluble in hexane, heptane, octane, decane, and tetrachloroethylene within the range of concentrations tested (34-900 mM). The compound was soluble in other non-polar organic solvents as well—*e.g.*, carbon tetrachloride and cyclohexane. Solutions based on these solvents were all able to levitate powders (*see*, *e.g.*, FIG. 4). Solutions with a concentration of up to 450 mM $Gd(DPM)_3TOPO$ had a sufficiently low viscosity to allow for fast equilibration of the powders in the MagLev device. $Gd(DPM)_3TOPO$ solutions of higher concentration (>450 mM) became markedly more viscous, increasing the time of the separation. The diluted $Gd(DPM)_3TOPO$ solution (450 mM; 23 vol% hexane and 77 vol% tetrachloroethylene) had density of 1.20 g cm^{-3} at 23 °C. The density was calculated (ρ = g/mL) by weighing 5 mL of the paramagnetic solution.

[0177] FIG. 4 shows separation of powdered mixtures (50:50 wt%; 45-50 mg) of lidocaine·HCl (top cloud) and caffeine (lower cloud) with MagLev using paramagnetic solutions with $Gd(DPM)_3TOPO$ (450 mM) dissolved in solvent mixtures of tetrachloroethylene in combination with different n-alkanes.

Example 7: Safety and Handling of the Paramagnetic Solution

[0178] The combination of hexane and tetrachloroethylene as solvents for the paramagnetic solutions were chosen because of their large difference in density (0.65 versus 1.62 g cm^{-3}). This difference allowed for adjustment of the density of the paramagnetic solution by changing the proportion of the solvents. A halogenated solvent was chosen because it is a non-polar organic solvent that has sufficiently high density (>1.5 g cm^{-3}). Both solvents are non-polar and are fully miscible with each other, and were also fully miscible with the two types of non-polar gadolinium complexes (*i.e.*, $Gd(DPM)_3TOPO$ and $Gd(acac)_3TOPO$) used. There were other beneficial properties of theses solvents: (i) They have boiling points that are significantly higher than room temperature (*e.g.*, n-hexane: 69 °C (other suitable n-alkanes was explored, *see* FIG. 4); and tetrachloroethylene: 121 °C), but they evaporated in a few minutes after the compounds were extracted from the MagLev device and placed on a filter paper. (ii) They have a low ability to solubilize polar substances (such as the salts of the drugs investigated). (iii) They have low chemical reactivity.

[0179] The toxicities of the solvents used in the paramagnetic solution were acceptable if handled with the correct safety procedures. The U.S. Hazardous Materials Identification System ("HMIS") ranks hexane as a "moderate hazard", and tetrachloroethylene as a "serious health hazard" for human health (the scale ranges from "minimum hazard" to "severe hazard").

[0180] Hexane is a flammable solvent used in, for example, glues, food-oil extraction, and chromatography. Inhalation of hexane in air for short periods of time can cause mild effects on the central nervous system, including, for example, dizziness, giddiness, slight nausea, and headache. Longer time periods of exposure (*e.g.*, inhalation or contact) to hexane is associated with effects on the nervous system, for example, nerve damage in humans.

[0181] Tetrachloroethylene is a nonflammable solvent that is used, for example, as a solvent in commercial dry-cleaning. The effect of chronic exposure to tetrachloroethylene can be severe, and the solvent is a suspected carcinogen. Precautions should be taken to avoid inhaling the fumes of the tetrachloroethylene and to avoid absorption the solvent through the skin. Tetrachloroethylene and carbon tetrachloride both are rated (HMIS) as "severe hazards" to human health, however, carbon tetrachloride is a more potent liver toxin.

[0182] In some embodiments, precaution should be taken to reduce the amount of evaporation of solvent from the paramagnetic solution. In some embodiments, the faster evaporation of the low-density hexane solvent relative to the high-density tetrachloroethylene solvent and the gadolinium chelate complexes can result in an increase in the density of the paramagnetic solution. In some embodiments, the change in density can interfere with the density calibration of the MagLev device. In some embodiments, the evaporation of the solvents can be minimized by reducing the time of the separation and by covering the top of the cuvette with aluminum foil. In some embodiments, the hexane can also be replaced with solvents with a higher boiling point, such as heptane (98 °C), octane (125 °C), nonane (151 °C), or decane (174 °C) to reduce the rate of evaporation of the solvent. For examples of separation of powders using MagLev with different n-alkanes, *see* FIG. 4.

Example 8: Image Processing

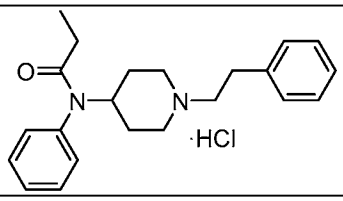
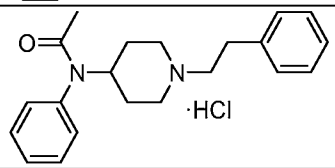
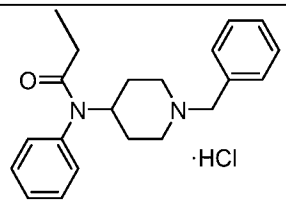
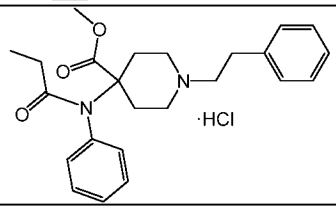
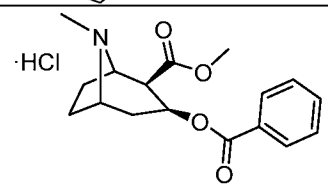
[0183] Images were edited using Adobe Lightroom. The white balance was manually set, selecting a spot in the darkest and brightest areas of the image for the calibration of the extremes, respectively. Edits were performed uniformly over the entire area shown in the figures, and with identical settings for every image of the series in FIG. 11A and FIG. 3B. The following parameters were manipulated: color (RGB or monochrome), exposure,

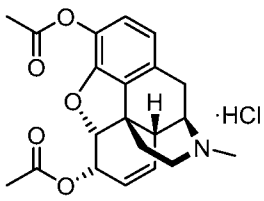
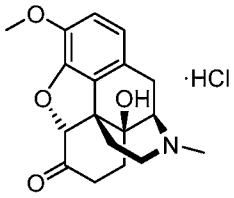
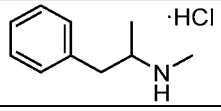
contrast, brightness (of highlights, shadows, whites, and blacks), clarity, dehazing, vibrance, and saturation. Unedited images are shown in some figures—white balance and exposure as set by the Nikon DSLR cameras used.

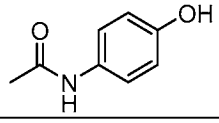
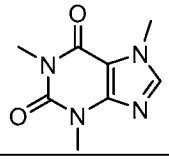
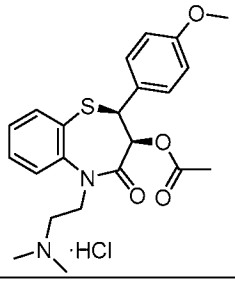
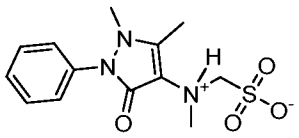
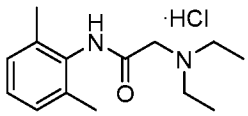
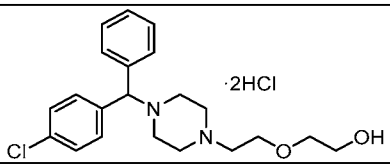
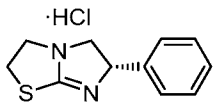
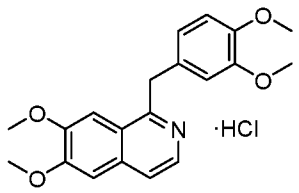
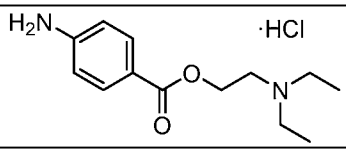
Example 9: Powdered Illicit drugs, Adulterants, and Diluents

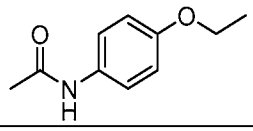
[0184] All illicit drugs were produced internally by the Drug Enforcement Administration ("DEA") for use as reference materials, except for the heroin·HCl, which came from a seized sample of South American origin. All experiments with illicit drugs were performed at facilities associated with the DEA. All adulterants and diluents were procured from Sigma-Aldrich, except the following: diltiazem hydrochloride (from EMD Millipore), D-mannitol (from Lancaster Synthesis, Inc.), papaverine·HCl (from ICN Biomedicals), and sucrose (from EMD Millipore).

Table 2: Trade names, structures, and IUPAC names of compounds.

Group	Compound				
	Cpd. No.	Trade Name	Structure	CAS No.	IUPAC Nomenclature
Active compounds	3	Fentanyl·HCl		1443-54-5	N-phenyl-N-[1-(2-phenylethyl)piperidin-4-yl]propanamide hydrochloride
	4	Acetyl fentanyl·HCl		11733 2-89-5	N-phenyl-N-[1-(2-phenethyl)piperidin-4-yl]acetamide hydrochloride
	5	Benzyl fentanyl·HCl		5156-58-1	N-(1-benzylpiperidin-4-yl)-N-phenyl-propanamide hydrochloride
	6	Carfentanyl·HCl		59708 -52-0 (for base)	Methyl 1-(2-phenylethyl)-4-[phenyl(propanoyl)amino]piperidine-4-carboxylate hydrochloride
	7	Cocaine·HCl		53-21-4	methyl (1S,3S,4R,5R)-3-benzoyloxy-8-methyl-8-azabicyclo[3.2.1]octane-4-carboxylate hydrochloride

Group	Compound				
	Cpd. No.	Trade Name	Structure	CAS No.	IUPAC Nomenclature
	8	Heroin·HCl		5893-91-4	[(4R,4aR,7S,7aR,12bS)-9-acetyloxy-3-methyl-2,4,4a,7,7a,13-hexahydro-1H-4,12-methanobenzofuro[3,2-e]isoquinoline-7-yl] acetate hydrochloride
	9	Oxycodone ·HCl		124-90-3	(4R,4aS,7aR,12bS)-4a-hydroxy-9-methoxy-3-methyl-2,3,4,4a,5,6-hexahydro-1H-4,12-methanobenzofuro[3,2-e]isoquinolin-7(7aH)-one hydrochloride
	10	Methamphetamine HCl		51-57-0	N-methyl-1-phenylpropan-2-amine hydrochloride

Group	Compound				
	Cpd. No.	Trade Name	Structure	CAS No.	IUPAC Nomenclature
Adulterants	11	Acetamino-phen		103-90-2	N-(4-hydroxyphenyl) acetamide
	12	Caffeine		58-08-2	1,3,7-trimethylpurine-2,6-dione
	13	Diltiazem· HCl		33286-22-5	[(2S,3S)-5-[2-(dimethylamino)ethyl] -2-(4-methoxyphenyl)-4-oxo-2,3-dihydro-1,5-benzothiazepin-3-yl] acetate hydrochloride
	14	Dipyrone / metamizole		5907-38-0	Sodium [(1,5-dimethyl-3-oxo-2-phenylpyrazol-4-yl)-methylamino] methanesulfonate
	15	Lidocaine· HCl		73-78-9	2-(diethylamino)-N-(2,6-dimethylphenyl) acetamide hydrochloride
	16	Hydroxyzi-ne· 2HCl		2192-20-3	2-[2-[4-[(4-chlorophenyl)-phenylmethyl]piperazin-1-yl]ethoxy]ethanol dihydrochloride
	17	Levamisole ·HCl		16595-80-5	(6S)-6-phenyl-2,3,5,6-tetrahydroimidazo[2,1-b][1,3]thiazole hydrochloride
	18	Papaverine ·HCl (not an adulterant per se—it is a byproduct of the heroin manufactur-ing process)		61-25-6	1-[(3,4-dimethoxyphenyl) methyl]-6,7-dimethoxyisoquinoline hydrochloride
	19	Procaine· HCl		51-05-8	2-(diethylamino)ethyl 4-aminobenzoate hydrochloride

Group	Compound				
	Cpd. No.	Trade Name	Structure	CAS No.	IUPAC Nomenclature
	20	Phenacetin		62-44-2	N-(4-ethoxyphenyl) acetamide

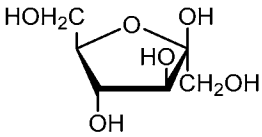
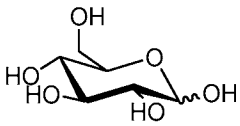
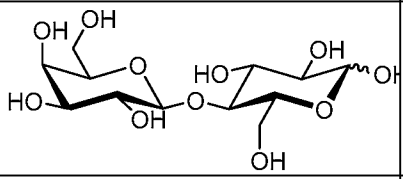
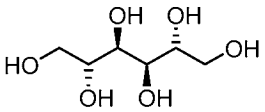
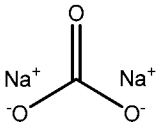
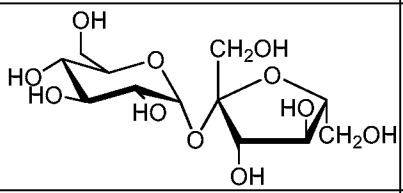
Group	Compound				
	Cpd. No.	Trade Name	Structure	CAS No.	IUPAC Nomenclature
Diluents	21	Dimethyl sulfone		67-71-0	(methanesulfonyl) methane
	22	D-Fructose		57-48-7	D-Fructose
	23	D-Glucose		50-99-7	D-Glucose
	24	α-Lactose		63-42-3	β-D-galactopyranosyl-(1→4)-D-glucose
	25	D-Mannitol		69-65-8	(2R,3R,4R,5R)-hexane-1,2,3,4,5,6-hexol
	26	Sodium carbonate		497-19-8	Sodium carbonate
	27	Starch from potato	A mixture of the polysaccharides amylose and amylopectin.	9005-25-8	Mixture of compounds
	28	Sucrose		57-50-1	β-D-Fructofuranosyl α-D-glucopyranoside
	29	Talc	$Mg_3Si_4O_{10}(OH)_2$	14807-96-6	Dioxosilane oxomagnesium hydrate

Table 3: The most common range of purity of illicit drugs at the retail level, and the most frequent adulterant and diluents associated with each type of drug. Note that oxycodone is a prescription drug, all other compounds are drugs from illicit sources.

Active Compound	Common range of drug content (wt%)	Most common adulterants and diluents
Fentanyl	US: N/A. The average is reported to be 5.1 wt%. Europe: N/A	Fentanyl is commonly found in mixtures sold as opioids, heroin, or cocaine. Fentanyl in often mixed with sugars.
Heroin	US: 6-60% Europe:15-41%	US: quinine, caffeine, diltiazem, lactose, and mannitol. Europe: caffeine and acetaminophen, and lactose.
Oxycodone	US: The content of oxycodone·HCl in OxyContin varies (8-30%) for different suppliers and dosing.	US: butylated hydroxytoluene, hypromellose, polyethylene glycol, polyethylene oxide, magnesium stearate, titanium dioxide, and compounds that gives the tablets color.
Cocaine	US: 39-65% Europe: 18-33%	US: levamisole, phenacetin, lidocaine, starch, and sodium carbonate. Europe: phenacetin, levamisole, caffeine, diltiazem, hydroxyzine and lidocaine.
Methamphetamine	US: 90-96% Europe: 36-70%	US and Europe: dimethyl sulfone, caffeine, sugars, and acetaminophen.

Example 10: Measurement of Density of Powders with MagLev

[0185] Disposable UV-grade methacrylate cuvettes (product no. Z188018, Sigma Aldrich, outer dimensions 12.7 × 12.7 × 45 mm, inner dimensions: 10 × 10 × 45 mm) were cut with a band saw to a height of 25 mm (approximately 2.5 mL capacity) to fit between the faces of the two magnets. This particular type of plastic cuvette showed good resistance to repeated exposures to the non-polar paramagnetic solutions used. The density gradient was mapped to obtain a standard curve, by recording the height of the levitating glass bead density standards (American Density Materials, Inc.) of known densities, with a ruler for reference of distance (*see* FIG. 7A). The powdered mixtures (300-1000 mg) were prepared by weighing and adding the individual compounds to a 10 mL glass vial and shaking and inverting it by hand for 5 minutes. From these powdered mixtures, samples with weights between 2-50 mg were extracted and added to the cuvette with the paramagnetic solution. The separation of the particles was imaged using a DSLR camera (Canon EOS Rebel T6i with a Canon EF 50 mm f/1.8 STM lens) for single time-point experiments and time-lapse imaging, with a ruler placed next to the cuvette as a reference of position. The levitating powders were illuminated with an external light source. The position of the middle of the centroid of the levitating fractions was used to find the density of the levitating compound from the standard curves.

[0186] The time of separation for the powders depended mainly on the following five reasons: (i) The sample size, because large amounts of powder took longer to separate than

small samples. (ii) The particle size, because small particles took longer time to separate than large ones. (iii) The concentration of gadolinium(III) in the paramagnetic solution, because a higher concentration of Gd^{3+} resulted in faster separation. (iv) The viscosity of the paramagnetic solution, because an increase in viscous drag on the particles resulted in slower separation. (v) The magnetic field strength, because higher magnetic field strength resulted in faster separation.

[0187] FIG. 7A shows the MagLev device was calibrated by measuring the position of glass beads of known density (with a ruler for reference). The standard curve was used to find the density of levitating fractions (*i.e.*, here, obtained from lidocaine·HCl and caffeine) in the MagLev device. FIG. 7B shows standard curves measured with glass bead density standards in solutions of $Gd(DPM)_3TOPO$ (450 mM) dissolved in solvent mixtures of different composition (vol%); C_2H_8 (hexane); C_2Cl_4 (tetrachloroethylene). FIG. 7C shows the standard curve measured with glass bead density standards in a solution of $Gd(acac)_3TOPO$ (1100 mM; as obtained from the synthesis in tetrachloroethylene, without further dilution).

Example 11: Density-based Separation of Powders using MagLev

[0188] A custom larger cuvette was made (*see* FIG. 2B and FIG. 8) that allowed access to the levitating powders with a pipette from the side of the MagLev after the powders had equilibrated. The custom cuvette was made by laser cutting (VersaLASER VL-300, Universal Laser Systems, Inc.) transparent poly(methyl methacrylate) ("PMMA") sheets (2 mm thick, McMaster-Carr) and by gluing the sheets together using acrylic adhesive (Weld-On #3 Adhesive, SCIGRIP). Pasteur pipettes were used to extract the different fractions of powders that had separated in the MagLev device (*see* FIG. 9). Each fraction was suction filtered on a grade 3 Whatman filter paper, and (at the same time) rinsed with hexane to remove any residues of the $Gd(DPM)_3TOPO$.

[0189] Powders of compounds of larger particle size (*e.g.*, fentanyl, acetyl-fentanyl, benzyl fentanyl, and heroin) reached their equilibrium positions in the paramagnetic solution faster than compounds of smaller particle size. Compounds present as small particles (*e.g.*, cocaine, methamphetamine, and lactose) moved more slowly in the paramagnetic solution (consistent with Stoke's law).

[0190] FIG. 8 shows a schematic diagram of the custom cuvette with dimensions viewed from the long edge and short edge, according to some embodiments.

[0191] FIG. 9 shows separation and extraction of the separate fractions of a powdered mixture (50 mg) of fentanyl-laced heroin in a MagLev device, according to some embodiments. The powdered mixture consisted of fentanyl·HCl (1.3 wt%), heroin·HCl (2.6 wt%), and α-lactose (96 wt%—bottom of the cuvette). The mixture was allowed to separate for 30 minutes before the different fractions were extracted with a Pasteur pipette (dashed white lines). The lactose did not levitate and sank to the bottom of the cuvette. The geometric shape of the cuvette (height: 25 mm) facilitated the insertion of the pipette without disturbing the levitated solids. The paramagnetic solution consisted of $Gd(DPM)_3TOPO$ (450 mM) dissolved in a mixture of 23 vol% hexane and 77 vol% tetrachloroethylene. The images were uniformly post-processed for contrast and clarity.

Example 12: A Model System Based on Lidocaine·HCl and Caffeine

[0192] All experiments with active compounds were performed at a DEA facility that had the necessary approvals and infrastructure for handling of such compounds. Active compounds were associated with significant legal oversight, permits, safety precautions, and limits on the type and amount of compound that can be procured. The bulk of the method development of the MagLev separation took place at Harvard University, which does not have approval to work with schedule I and II drugs.

Table 4: Requirements for handling of schedule I and II drugs in the U.S.

	Schedule I*	Schedule II**
Registration	Required	Required
Receiving Records	Order Forms	Order Forms
Prescriptions	No	Written prescription
Refills	No	No
Distribution Between Registrants	DEA order forms	DEA order forms
Security	Locked cabinet or other secure storage	Locked cabinet or other secure storage
Theft or Significant Loss	Report and complete DEA form	Report and complete DEA form

*Definition of Schedule I compounds (U.S.): Drugs, compounds, and chemicals without any currently accepted use in medicine, and with a high potential for abuse, *e.g.*, cannabis, lysergic acid diethylamide (LSD), methaqualone, peyote, heroin, and 3,4-methylenedioxymeth-amphetamine (ecstasy).

**Definition of Schedule II compounds (U.S.): Drugs, compounds, and chemicals with a high potential for abuse, and a high risk of users developing strong psychological/physical dependence, *e.g.*, fentanyl, cocaine, methamphetamine, hydromorphone, methadone, oxycodone, methadone, Ritalin, and Adderall.

[0193] To facilitate the development of the methodology and the investigation of the dynamics of the separation in the MagLev device, a model system was developed that does not contain controlled compounds. The model system consisted of a binary mixture of two

compounds, lidocaine·HCl and caffeine, both of which are minimally regulated (along with additional benefits) compared to active compounds (chemistry laboratories can buy them without special approval). This model system was chosen for the following reasons: (i) The two compounds were water-soluble and, thus, they mimicked many active compounds; (ii) hydrochlorides, such as lidocaine·HCl, were the common salt forms found in seized mixtures of powdered illicit drugs; (iii) both compounds were commonly found as adulterants in powdered mixtures of illicit drugs; (iv) laboratories could procure them without special permits and documentation; (v) they had distinctly different densities; (vi) their particle sizes were different when observed by eye; (vii) they were inexpensive (Sigma Aldrich: lidocaine·HCl, Prod.#: PHR1257-500MG, $127 per gram; caffeine, Prod.#: C0750-5G, $4 per gram); and (viii) their toxicity was acceptable; *i.e.*, a dust mask was sufficient protection to avoid inhalation of particles when the dried powders were handled (which is important in the case of lidocaine·HCl).

Example 13: Scanning Electron Microscopy Imaging of Powders

[0194] To obtain SEM images (*see* FIG. 12C), a small amount (<1 mg) of powdered of lidocaine·HCl and caffeine were dispensed (on separate SEM stubs) with a spatula directly onto carbon tape (Ted Pella, 16086-12) that had been manually applied to standard SEM stubs (Ted Pella, 16111). The powders were gently pressed with a spatula into the carbon tape to promote adhesion. Field emission electron microscopy was performed on a Zeiss Ultra Plus FESEM using the in-lens detector at an imaging voltage of 0.8 kV and the SE2 secondary electron detector at an imaging voltage of 6.5 kV. ImageJ was used to analyze the size of the crystals in the images.

Example 14: ^{1}H NMR Analysis of Fractions of Powders Separated by MagLev

[0195] A mixture of lidocaine·HCl and caffeine (50:50 wt%) was levitated in the MagLev device until the powders reached their equilibrium levitation heights. The powders were carefully extracted from the cuvette using Pasteur pipettes (guided by pivoting of the hand) and collected by suction filtration on a grade 3 Whatman filter paper. The residue was washed three times with 40 mL portions of solvent (hexane), air-dried, and gently scraped off the filter paper with a spatula and stored in an air-tight glass vial (*e.g.*, up to five days) until characterized. For ^{1}H NMR, 3 mg of the residue was dissolved in 0.6 mL of DMSO-d_6 and transferred to a NMR tube for NMR analysis. ^{1}H NMR spectra (*see* FIG. 12E) were recorded on an Agilent DD2 600 MHz NMR spectrometer, using standard pulse programs.

Example 15: FTIR-ATR Analysis of Fractions of Powders Separated by MagLev

[0196] The powdered samples that contained powdered lidocaine·HCl and caffeine (same washing procedure as for the ^{1}H-NMR analysis) were analyzed in their dry, powdered state with FTIR (*see* FIG. 12F) with an ATR diamond window (Bruker Platinum, Bruker). Spectra were measured between 4000-400 cm^{-1} at a resolution of 1 cm^{-1} with 64 sample and background scans. The samples that contained fentanyl·HCl and α-lactose (same washing procedure as for the ^{1}H-NMR analysis of lidocaine and caffeine) were analyzed with an FTIR-ATR (Nicolet iS19 FTIR with a smart Golden Gate ATR, Thermo-fisher) between 4000-455 cm^{-1} at a resolution of 4 cm^{-1} with 64 sample and background scans. The pure compounds (controls) were analyzed without first exposing them to any paramagnetic solutions.

Example 16: Analysis of Powders Containing Illicit Drugs Using MagLev

[0197] MagLev enabled the separation of powdered mixtures of illicit drugs (*e.g.*, cocaine, methamphetamine, heroin, fentanyl and its analogs), adulterants, and diluents based on density, and allowed the presumptive identification of individual components. In some embodiments, small samples (mass <50 mg), with low weight percentages of illicit drugs, present a particular challenge to analysis for forensic chemists. The MagLev device—a cuvette containing a solution of paramagnetic gadolinium(III) chelate in a non-polar solvent, placed between two like-poles-facing NdFeB magnets—allowed separation of seven relevant compounds simultaneously. In particular, initial separation with MagLev, followed by characterization by FTIR-ATR, enabled identification of fentanyl in a sample of fentanyl-laced heroin (1.3 wt% fentanyl, 2.6 wt% heroin, and 96.1 wt% lactose). MagLev allowed identification of unknown powders in mixtures and enabled confirmatory identification based on structure-specific techniques.

[0198] The abuse of drugs is a major public health problem, with fatalities attributed to overdoses numbering 7,600 in the E.U. (78% involving opioids) and 70,000 in the U.S. (86% opioids) in 2017. A potent subgroup of these compounds are the synthetic opioids (mainly fentanyl and its analogs) that were involved in 30,000 deaths in the U.S. In some embodiments, "opioids" are defined as molecules that interact with the opioid receptors in neural and intestinal cells. In some embodiments, "opiates" are opioids of natural or semi-natural origin.

[0199] Fentanyl—a painkiller and anesthetic that is widely used in medicine—has particular relevance in law enforcement because it is the predominant synthetic opioid found in seized samples of drugs of abuse. Fentanyl and its analogs can be orders of magnitude

more potent than natural opioids; for example, the activities of these compounds in suppression of pain, relative to morphine, are: morphine (potency ≡ 1x), oxycodone (1.8×), acetyl fentanyl (16×), fentanyl (100×), and carfentanyl, (10,000×). These compounds are mainly used as additives in products that are marketed recreational, or "street", drugs, such as, for example, "heroin" and "cocaine". An addict may typically use 0.3-1.0 mg of fentanyl to achieve a high; a dose of 2.0-5.0 mg may cause death. In the U.S. (2017), the DEA found that the average content of fentanyl in drugs obtained from street-level retail was 5.1 wt% (with a total range of 0.1-97.8 wt% for all confiscated drugs). Fentanyl hydrochloride is a prominent fentanyl salt in seized samples, while the citrate salt is found in a minority of confiscated drugs.

[0200] To moderate potency, and to increase profit margins, drugs are commonly diluted with adulterants, *i.e.*, semi-active compounds that are added to enhance the effect of the drugs or simply mimic their properties. For example, because drug users test the bitterness of mixtures to judge the content of heroin, acetaminophen and caffeine are added to maintain the bitterness of the mixture when heroin—which is bitter—is diluted. Diluents (non-active compounds, such as lactose, dimethyl sulfone, and glucose) are added to lower the concentration of the drug, and to make it easier to handle and use.

[0201] To identify a drug according to forensic standards of analysis, two to three different analytical methods can be used. Techniques with molecular specificity—X-ray diffractometry and IR, NMR, Raman, and mass spectrometry—are given the highest ranking. GC-MS is the workhorse in modern forensic drug laboratories (*e.g.*, in most U.S. federal, state, and municipal laboratories—depending on the state), but the cost, the lack of portable systems, and the technical skill needed to handle this instrument prohibit large-scale use in the field. Most separations (capillary electrophoresis, gas chromatography, liquid chromatography, and other less-molecularly-specific techniques) are considered intermediate in value for identification. Other methods that provide more limited information about the molecular structure are in the third, lowest, category. When an appropriate combination of methods is used to confirm the presence of a compound (*e.g.*, at least two techniques, with one from category A and the second from categories A, B, or C, or, alternatively, three techniques if at least two are from category B and the additional technique is from B or C), and when the sampling procedure adheres to defined protocols, the presence of the compound can be considered to have been identified. This level of identification is referred to as "confirmatory identification."

Table 5: Recommended techniques for identification of illicit drugs, according to some embodiments. The methods were ranked in categories according to the ability to identify the specific molecular structures. The categorization is defined by the international forensic organization Scientific Working Group for the Analysis of Seized Drugs ("SWGDRUG"). Category A techniques provided structural information about molecules. Category B techniques measured chemical or physical information, and Category C offered general information, or class information, about the compounds that are present.

Category A (Highest selectivity for molecular structure)	Infrared Spectroscopy
	Mass Spectrometry
	Nuclear Magnetic Resonance Spectroscopy
	Raman Spectroscopy
	X-ray Diffractometry
Category B (Intermediate Selectivity)	Capillary Electrophoresis
	Gas Chromatography
	Ion-Mobility Spectrometry
	Liquid-Chromatography
	Microcrystalline Tests*
	Supercritical Fluid Chromatography
	Thin-Layer Chromatography
	Ultraviolet/Visible Spectroscopy (full spectrum)
	Macroscopic Examination (Cannabis only)
	Microscopic Examination (Cannabis only)
Category C (Lowest Selectivity)	Color Tests
	Fluorescence Spectroscopy
	Immunoassay
	Melting Point
	Pharmaceutical Identifiers (*i.e.*, information on packaging)

*Chemical tests based on the addition of chemical reagents that form characteristic types of microcrystals when a specific drug is present. The crystals are identified by observation with light microscopy.

[0202] In some embodiments, in the U.S., in confirmatory identification can only be performed by an expert (*e.g.*, a forensic chemist). In some instances, a police officer cannot be admitted as an expert witnesses in court for chemistry or forensics and, therefore, the "opinion" of the police officer cannot be entered as fact. Thus, a measurement performed by a law enforcement officer with a confirmatory technique is assigned a standing similar to that of a presumptive technique. However, the use of techniques of high molecular specificity by law enforcement officers have the benefit of reducing the number of false positive and negatives that are inherent to most other presumptive identification techniques.

[0203] In some embodiments, MagLev has the potential to be used for presumptive identification, based on compound density. In some embodiments, presumptive identification is the lowest level of specificity (Category C in Table 5), but encompasses the most common group of analytical methods used to screen compounds in the field (outside of an analytical laboratory). Immunoassays and colorimetric tests are other examples; these techniques provide weak evidence of molecular identity, but are easily used in resource-limited

circumstances (*e.g.*, border inspection stations and mail-sorting facilities). MagLev has, however, the potential to enable more specific techniques because of its ability to separate dilute compounds in mixtures of powders. In some embodiments, MagLev has the potential to be used by forensic organizations for analysis of seized illicit drugs.

[0204] MagLev was used to determine three characteristics of a powdered sample: (i) the minimum number of compounds present in the sample, (ii) the densities of these separately levitating compounds (or mixtures of overlapping compounds) (*see* FIGS. 10A-C and FIGS. 11A-B), and (iii) qualitatively, an estimate of the relative amounts of these compounds (*see* FIG. 12D). To finish the presumptive identification, the densities measured for the levitating fractions were compared with reference materials (pure compounds) using a look-up table (*see* Table 6). MagLev generated more information from the same sample than most techniques used for presumptive identification and measured the density of multiple compounds, including those present in small amounts, for a range of chemical structures in a one-step procedure. MagLev both allowed for the separation and isolation of the compounds present in a mixture, and facilitated an increase in the specificity of more detailed spectroscopic methods.

Table 6: The densities of different active compounds, adulterants, and diluents found in mixtures of illicit powdered drugs, according to some embodiments. The densities represent the values reported in literature, and measured with the MagLev device as described in some embodiments herein. N/A= not available.

	Compound	Density reported in literature ($g\ cm^{-3}$)	Density measured with MagLev* ($g\ cm^{-3}$)	%-difference in density measured with Maglev relative to reported values**
Active compounds	Fentanyl·HCl	N/A	1.19	N/A
	Fentanyl citrate	1.23	N/A	N/A
	Fentanyl base	1.16	N/A	N/A
	Acetyl fentanyl·HCl	N/A	1.18	N/A
	Benzyl fentanyl·HCl	N/A	1.14	N/A
	Cocaine·HCl	1.34	1.32	5.6
	Heroin·HCl	1.38	1.34	-2.9
	Methamphetamine·HCl	0.91	1.10	20.1
Adulterants	Acetaminophen	1.29	1.27	-1.6
	Caffeine	1.39	1.36	-2.2
	Diltiazem·HCl	1.24	1.30	4.8
	Dipyrone / Metamizole sodium	1.39	1.38	-0.7
	Lidocaine·HCl	1.20	1.19	-0.8
	Hydroxyzine·2HCl	1.24	1.22	-1.6
	Levamisole·HCl	1.31	1.45	10.7
	Papaverine·HCl***	1.33	1.30	-2.2
	Procaine·HCl	1.16	1.23	6.0
	Phenacetin	1.24	1.21	-2.41

	Compound	Density reported in literature ($g\ cm^{-3}$)	Density measured with MagLev* ($g\ cm^{-3}$)	%-difference in density measured with Maglev relative to reported values**
Diluents	Dimethyl sulfone	1.44	1.43	-0.7
	β-D-(-)-Fructose	1.6	1.58	-2.5
	D-(+)-Glucose	1.54	1.51	-1.9
	α-Lactose	1.54	1.50	-2.6
	D-Mannitol	1.51	1.51	0
	Sodium carbonate	2.54	>1.77	N/A
	Starch from potato	1.5	1.48	-2.6
	Sucrose	1.59	1.58	-0.6
	Talc	2.82	>1.55	N/A

*The densities of the compounds were determined by recording the height (distance above the bottom magnet) that each levitating fraction levitated between the two magnets. The middle of the centroid formed by each levitating cloud was defined as the height of levitation of that particular fraction. The recorded height was converted to a value of density using an experimentally determined standard curve.
** The discrepancies in densities between the values reported in literature and measured with MagLev can, in some embodiments, be caused by different factors. For example, in some embodiments, X-ray diffractometry is often performed on single crystals that are perfectly crystalline; illicit drug samples are known to contain compounds that are not perfectly crystalline. In addition, the densities measured with MagLev were determined from levitating clouds that typically consisted of several hundred particles that in some cases were crystalline or amorphous (or a mixture of both states), or in different states of hydration or crystal polymorphism, etc.
*** Papaverine is technically a product of heroin manufacturing, not an adulterant or diluent.

[0205] In some embodiments, determining the composition of illicit drugs in the field faces at least four hurdles: (i) the technical and procedural training required to ensure correct handling of the sample, (ii) access to appropriate instruments, (iii) the risk of exposure to the drugs, and (iv) the highly variable composition of the drug mixtures. For these and other reasons, seized samples are often not analyzed for their constituents in the field, but only later at a local law enforcement facility, or at a well-equipped and competently staffed central laboratory. Shipping to, and analysis in, central laboratories can introduce long delays in the identification of molecular constituents of mixtures of drugs (*e.g.*, backlogs in analysis are common).

[0206] In some embodiments, mixtures of illicit drugs can contain a wide range of compounds. With this in mind, separation of active compounds (with a range of chemical properties) commonly found in samples seized by law enforcement was conducted, including the hydrochloride salts of fentanyl, acetyl fentanyl, cocaine, heroin, and methamphetamine (*see* FIGS. 10A-Cand FIGS. 11A-B). Five relevant powdered mixtures were separated, each composed of commonly encountered active compounds, adulterants, or diluents (*see* FIG. 10A and FIGS. 11A-B). Although cocaine·HCl (1.32 $g\ cm^{-3}$) and heroin·HCl (1.34 $g\ cm^{-3}$) did not separate completely under the conditions described here (*see* FIG. 11A and Table 6), their separation by density can be improved by changing a number of parameters.

[0207] In some embodiments, the synthetic opioids can be especially challenging to detect due to their high potency, which enables (and requires) high dilution (≤5 wt%) of the active components and, thus, makes the analyses of these opioids in small samples (≤50 mg) particularly difficult. For example, a fentanyl compound may be present only as a few crystals in a 50 mg sample.

[0208] Existing portable methods for detection of fentanyl include colorimetric tests, microcrystalline tests, electrochemistry, immunochemistry, near-infrared spectroscopy, surface-enhanced Raman spectroscopy, Raman spectroscopy, and FTIR spectroscopy. Common portable methods currently used in the field by law enforcement personnel for general detection of drugs are colorimetric tests, handheld Raman (*e.g.*, Thermo Scientific TruNarc or Chemring Detection Systems PGR-1064), and FTIR (*e.g.*, Thermo Scientific TruDefender FTXi and Smiths Detection HazMatID Elite). Both Raman and FTIR-ATR (which are considered more sensitive and accurate than colorimetric tests) have limits-of-detection of approximately 5 wt%, and are therefore not sensitive enough to detect dilute drugs directly in the mixtures of illicit drugs, adulterants, and diluents.

[0209] MagLev was used to separate, and to measure the density and abundance of, compounds in mixtures of powdered illicit drugs (*e.g.*, fentanyl, heroin, cocaine, and methamphetamine hydrochlorides), together with adulterants and diluents. This analysis focused on the psychoactive components in these mixtures of drugs (*i.e.*, the "active" compounds). Fentanyl and its analogs were of particular interest, for which MagLev was used as a technique that both provides presumptive (*i.e.*, tentative) identification of the compounds (based on density) and facilitates subsequent identification by other techniques. Combining MagLev (to separate mixtures, and to allow presumptive identification) and molecular spectroscopy (using whichever technique is most appropriate) for molecular identification provided a method of confirming the identity of drugs in mixtures (*see* FIGS. 1A-C and FIGS. 11A-B). These methods were particularly useful when analytical methods must be rapid and simple (*e.g.*, in screening at forensic laboratories, and in the field) and the active compound is dilute (0.1-5.0 wt%), as is often the case for fentanyl and its analogs in street-level drugs. In some embodiments, dilution of powders is defined as the process of mixing one or more powders with each other to achieve a reduction of the relative content of one or more compounds (and, consequently, to increase the volume of the drug-containing mixture to facilitate handling). The type of MagLev device used in some embodiments is shown in FIG. 2A.

[0210] FIG. 10A shows successful separation, presumptive identification, and confirmatory identification of dilute fentanyl, in a mixture of heroin and a diluent (lactose), according to some embodiments. An image was taken after 30 minutes of separation by MagLev of a powdered mixture of fentanyl-containing heroin (fentanyl·HCl (1.3 wt%), heroin·HCl (2.6 wt%), and α-lactose (96.1 wt%)). The separation was performed in a custom-made cuvette (shaped to allow easy entry of a pipette) filled with a paramagnetic solution of $Gd(DPM)_3TOPO$ (450 mM) in a mixture of 23 vol% hexane and 77 vol% tetrachloroethylene. The image was uniformly post-processed for contrast and clarity; the original image is shown in FIG. 10B. To generate FIG. 10C, the separated fractions were extracted using a Pasteur pipette, and were subsequently rinsed with hexane under suction filtration to remove any remaining gadolinium complex and air-dried. FIG. 10C shows FTIR-ATR spectra (normalized to the highest peak) measured from the powdered mixture before separation (top spectrum). The extracted fractions containing fentanyl and lactose (third and fifth spectra from the top, respectively), and the pure compounds (second and fourth spectra from the top, respectively) are also shown in FIG. 10C.

[0211] FIG. 11A shows time-lapse photographs of the separation of mixtures of powdered illicit drugs, adulterants, and dilutants (2.5-9.5 mg of each compound) using MagLev. The paramagnetic solution used in the device was $Gd(DPM)_3TOPO$ (450 mM) dissolved in a mixture of 23 vol% hexane and 77 vol% tetrachloroethylene. Photographs were uniformly post-processed for contrast and clarity; the original images are shown in Figure 11B.

[0212] MagLev was used to separate dilute (1.0-2.6 wt%) compounds from powdered mixtures, including: (i) 1.3 wt% fentanyl·HCl, 2.6 wt% heroin·HCl, and 96.1 wt% α-lactose (*see* FIGS. 10A-C and FIG. 9); (ii) 1.0 wt% lidocaine·HCl and 99.0% caffeine (*see* FIG. 12B); and (iii) 99.0 wt% lidocaine·HCl and 1.0 wt% caffeine (*see* FIG. 12B). In some embodiments, FTIR-ATR could not detect the presence of fentanyl·HCl in the first mixture before separation of the mixture, but it provided clear confirmatory identification of fentanyl·HCl in the fraction having the expected density (as compared to pure fentanyl) for fentanyl·HCl after separation (*see* FIG. 10B). In some embodiments, the lower limit in weight percent for a component of mixture that can be separated by MagLev was below 1 wt% (*see* FIG. 12B).

[0213] The separation of lidocaine·HCl from caffeine (*see* FIGS. 12A-G)—demonstrated herein as model constructed from easily accessible, low-risk, but relevant adulterants—demonstrated that MagLev can facilitate identification of dilute compounds in powdered

mixtures by separating these fractions (in some embodiments, as few as five 100-200 μm crystals, approximately 0.1 mg) from other compounds in 50 mg samples consisting of hundreds to thousands of particles of other compounds (*see* FIG. 12B).

[0214] This model system facilitated the development of MagLev for uses with powdered mixtures of illicit drugs, and also for the investigation of the dynamics of separation of particulates in a MagLev device. MagLev separated the binary mixtures of lidocaine·HCl and caffeine of seven different compositions into two fractions, and the amount of compounds in each fraction (quantified by image analysis, *see* FIG. 12D) agreed quantitatively with the known compositions of the samples. The size of the crystals influenced the kinetics of separations: both compounds consisted of rod-shaped crystals (length of crystals (*see* FIG. 12C): a) lidocaine—minimum 20 μm; quartile 1st 61 μm, 2nd 92 μm, and 3rd 135 μm; maximum 292 μm; b) caffeine—minimum 4 μm; quartile 1st 12 μm, 2nd 18 μm, and 3rd 28 μm; maximum 89 μm; n = 200). Caffeine, however, was present mostly as large aggregates (500-2000 μm, by visual estimation from FIG. 12B) that consisted of small crystals.

[0215] MagLev separated crystals of both compounds within approximately 20 minutes, but some non-aggregated (small) particulates of caffeine remained suspended after this period (observed as less transparent paramagnetic solutions in samples of high (≥75 wt%) caffeine content), due to the high ratio of drag-to-magnetic-force for small particles. The time of separation of the illicit drugs (*see* FIG. 11A) were comparable to that of caffeine or lidocaine, indicating that the particle sizes found in the powders of the illicit drugs are of a similar range.

[0216] Following separation using MagLev, the fractions were extracted and characterized by NMR (*see* FIG. 3E) and FTIR-ATR (*see* FIG. 3F). The close match of the spectra of the extracted fractions to the standards (pure compounds) suggested excellent separation of crystals of these two compounds using MagLev. The separation was near complete; residual crystals due to incomplete separation may still be present in the fractions, but were at or below the limit-of-detection of either spectroscopic method. The separation with MagLev also enabled unambiguous identification of caffeine with FTIR-ATR—this compound could not be identified in the mixture before separation (*see* FIG. 3F).

[0217] FIGS. 12A-G show a model system for the investigation of MagLev separation of powdered mixtures and the following characterization with spectroscopic techniques, according to some embodiments. FIG. 12A shows MagLev separation (30 minutes) of a mixture of lidocaine·HCl and caffeine (95:5 wt%; 50 mg) in a cuvette filled with the

paramagnetic solution, and extraction using a Pasteur pipette, according to some embodiments. FIG. 12B shows MagLev separation (20 minutes) of powdered mixtures (50 mg) of lidocaine·HCl (top clouds) and caffeine (bottom clouds) in different proportions (wt%), according to some embodiments. The paramagnetic solution in FIGS. 12A-B consisted of $Gd(DPM)_3TOPO$ (450 mM) dissolved in a solvent mixture of 23 vol% hexane and 77 vol% tetrachloroethylene. Height of cuvettes: 25 mm. FIG. 12C shows scanning electron micrographs of crystals of lidocaine·HCl and caffeine (pure compounds), according to some embodiments. FIG. 12D shows the projected, two-dimensional areas of the levitating fractions of lidocaine·HCl and caffeine, and their combined area, plotted against the chemical composition of mixtures, according to some embodiments. The area was measured in images with a physical ruler for reference of distance with the software ImageJ. FIG. 12E shows ^{1}H-NMR (600 MHz) characterization of a mixture (50 mg) of lidocaine·HCl and caffeine (50:50 wt%) and the fractions after separation (30 minutes) in the MagLev, according to some embodiments. The individual fractions were extracted as in FIG. 3A and rinsed with hexane during suction filtration and air-dried on a filter paper. Part of the residue (3.0 mg) was dissolved in DMSO-d_6 (0.6 mL)—no lidocaine was detected with ^{1}H NMR in the caffeine-rich fraction, and no caffeine in the lidocaine·HCl-rich fraction. Signals from the solvent, DMSO, (at 2.5 ppm) and water (at 3.3 ppm) were present. FIG. 12F shows FTIR-ATR characterization (normalized to highest peak) of the samples purified in FIG. 12E except that the residue was characterized as a dry powder. Pure compounds were used as controls for both the ^{1}H NMR and FTIR-ATR characterization. The photographs in FIGS. 12A-B were uniformly post-processed to enhance contrast and clarity; FIG. 12G shows the originals.

[0218] MagLev was used to measure the densities of 23 compounds (6 active compounds, 10 representative adulterants, and 9 diluents) found in mixtures of powdered drugs (*see* FIGS. 10A-10C, FIGS. 11A-B, FIG. 13, and Table 6). Most compounds reached their equilibrium positions in the MagLev device in 5-30 minutes (*see* FIG. 11A and FIG. 13), depending on the size of the grains or crystals.

[0219] FIG. 13 shows time-lapse photography of individual drugs (2-9 mg of powder) levitating in a MagLev device, according to some embodiments. The paramagnetic solution consisted of $Gd(DPM)_3TOPO$ (450 mM) dissolved in a mixture of 23 vol% hexane and 77 vol% tetrachloroethylene. The white dashed circle in the lower right image highlights the area where methamphetamine·HCl equilibrated in the MagLev. The images were uniformly post-processed for contrast and clarity.

[0220] In some embodiments, MagLev are performed on suspended objects or particles. Most illicit drugs, adulterants, and diluents are readily water-soluble (with the notable exceptions of cocaine, phencyclidine, and heroin in their free-base forms). Thus, in some embodiments, their separation and analysis with MagLev requires non-polar paramagnetic solutions to suspend and levitate them. Few existing paramagnetic chelates are soluble at high concentration in non-polar solvents, while still maintaining a low viscosity of the solution. Therefore, in some embodiments, mixtures of hexane ($\rho = 0.66$ g cm^{-3}) and tetrachloroethylene ($\rho = 1.62$ g cm^{-3}) were used as the solvent for the gadolinium(III) chelate complexes, because mixtures of these solvents spanned the range of densities useful for analysis of powdered drugs, and had suitable characteristics (*e.g.*, low polarity, appropriate density, low viscosity, and toxicity). None of the compounds (illicit drugs, adulterants, or diluents) investigated in these Examples (*see* Table 3) dissolved in the non-polar paramagnetic solutions used, as judged by eye (*see* FIG. 10A, FIG. 11A, FIGS. 12A-G, and FIG. 13).

[0221] Using MagLev, it was possible to carry out presumptive identification of multiple compounds simultaneously (*see* FIG. 4), and, thus, to increase the likelihood of a correct identification of the components (using a lookup table of known densities for reference) in samples, because certain combinations of drugs and/or adulterants are more common than others. For example, methamphetamine is commonly found in binary powdered mixtures with dimethyl sulfone.

[0222] FIG. 4 shows separations of powdered mixtures (50-60 mg) of adulterants and diluents using MagLev, according to some embodiments. The left image shows lidocaine·HCl, dimethyl sulfone, potato starch, D-(+)-glucose, and β-D-(-)-fructose in a solution of $Gd(DPM)_3TOPO$ (450 mM) dissolved in tetrachloroethylene. The right image shows hydroxyzine·2HCl, acetaminophen, diltiazem·HCl, levamisole·HCl, D-mannitol, sucrose, and sodium carbonate (at bottom) separated in a paramagnetic solution of $Gd(acac)_3TOPO$ (1100 mM) in tetrachloroethylene. Table 6 lists the densities of the levitating compounds, according to some embodiments. Photographs were uniformly post-processed for contrast and clarity.

[0223] For powdered mixtures of illicit drugs, in some embodiments, a mixture of 5-12 compounds in one sample is not uncommon.

[0224] Figure 14, right image, demonstrates application of MagLev in the simultaneous separation of seven different adulterants and diluents from a powdered mixture, according to some embodiments. Most compounds in powdered mixtures of illicit drugs have densities in

the range of 1.10-1.58 g cm^{-3} (*see* Table 6). The procedure for MagLev used in these Examples can measure a larger range of density (*e.g.*, 0.60-1.77 g cm^{-3}; *see* FIGS. 7A-C).

[0225] The densities of compounds determined by MagLev largely agreed with values reported in the literature (*see* Table 6), which were measured by, for example, XRD and calculated from the dimensions and occupancy of the unit cells, or by gas pycnometry. The density measurements deviated from literature values by less than 20.2%. The largest differences were recorded for the hydrochlorides of methamphetamine (20.1%), levamisole (10.7%), procaine (6.0%), cocaine (5.6%), and diltiazem (4.8%). Without wishing to be bound by theory, these differences may be due to impurities or different forms of the drug present in samples (*e.g.*, as hydrates, solvates, or carbonates, admixture with other compounds with similar density, particles that are partly amorphous instead of fully crystalline, crystals that included polymorphs, or other issues). Nonetheless, these differences in density were largely irrelevant for separations, as long as the compounds do separate. In some embodiments, the values of densities for relevant compounds can, however, be important for the presumptive identification of compounds that have not been previously separated by MagLev, and should be better established (both in pure samples, and as encountered in different mixtures of illicit drugs).

[0226] To minimize errors, for compounds that have been previously characterized and that have been documented in look-up tables, density-based presumptive identification with MagLev can be performed under the same set of conditions (*e.g.*, type of MagLev device, type of paramagnetic chelate complex, and concentration of solution) used for previous characterizations.

[0227] In some embodiments, MagLev is simple to use and portable. It thus, in some embodiments, offers a new method for screening drugs outside of a well-equipped forensic laboratory (*e.g.*, at crime scenes and law enforcement sites). Because, in some embodiments, separation by MagLev is rapid, it could shorten the time required for presumptive identification of illicit drugs at crime scenes. In some embodiments, complementary and more precise techniques could subsequently be used for confirmatory identification, because MagLev is non-destructive. In some embodiments, the synergy of MagLev with FTIR-ATR is attractive for analysis of drugs because both techniques are portable, require little training to use, and work well with powdered compounds. In some embodiments, the two are also complementary because MagLev compensates for the low sensitivity of FTIR-ATR in complex mixtures, by separating and concentrating fentanyl or other compounds of primary interest. In some embodiments, uses of MagLev in this type of application can be optimized

in the laboratory using easily obtained compounds—*e.g.*, lidocaine·HCl and caffeine—that are relevant to illicit mixtures of drugs, as components of model systems, and can thus avoid the often prohibitive regulations placed on the use of most active compounds (*see* Table 4).

[0228] In some embodiments, producers of illicit drugs make new analogs more quickly than these compounds can be "scheduled" as illegal compounds. Before a drug can be scheduled, multiple agencies must determine if it has a "strong index of suspicion." For example, for synthetic opioids, there must be a strong suspicion that the drug causes miosis, depressed respiration, changes in mental status, and additional signs of opioid toxicity. In some embodiments, a strength of MagLev is that the method is non-specific to the molecular structure or the biological activity; an additional, more structure-specific technique (*e.g.*, FTIR or, Raman-spectroscopy, or mass-spectrometry) may be required to enable the assignment of new compounds to a class. In some embodiments, this characteristic also makes MagLev suitable for providing a rapid early warning of a new or unfamiliar compound whose density (and probably structure) varies only slightly from those of compounds of a previously known class of compounds (new analogs of fentanyl are an example); through separation, MagLev enables the molecular characterization of those compounds by other techniques. In some embodiments, MagLev could aid in the detection of new designer drugs, unconventional mixtures of drugs, fentanyl-laced drugs of inconsistent and unexpectedly high concentration, and harmful adulterants on the illegal market. Circumventing detection by MagLev would require additional and unfamiliar efforts on the part of providers of street drugs. In some embodiments, MagLev enables the characterization of dilute compounds in mixtures of powders using techniques that would otherwise not be able to identify the molecular structure of dilute compounds in mixtures of powders.

Example 17: Two Methods for Fingerprinting Powdered Mixtures of Drugs after Levitation with MagLev

[0229] In some embodiments, MagLev separation coupled with time-lapse photography, image analysis, and machine learning (including signal processing techniques) provides a method to obtain unique "fingerprints" of mixtures of powdered drugs of prescription or illicit origin. The separation of drug particles from mixtures were performed in a cuvette filled with an apolar paramagnetic solution (such that the dissolution of hydrophilic compounds was avoided or significantly reduced) that is placed between two permanent magnets held in position by a frame. The individual components of the mixtures equilibrated (levitated) at their equivalent density (corresponding to a specific position between the magnets—a ruler was placed next to the cuvette for reference) in the density gradient

generated between the magnets, forming levitating "clouds" of particles of a more or less spherical shape. The n-position was defined as the middle of the centroid of the levitating clouds. Three different methods were used to generate the fingerprints:

The first method of fingerprinting was based on the measurement of density and the amount of substance, and on modelling (*see* Method 1 below) the particle size distribution (taking into account the change in size of the clouds over time, the shape of the cuvette, and viscosity of the paramagnetic solution). This method relied on both the dynamic separation process (to determine characteristic particle sizes) and the final state of rest of the separated particles (to determine the density of the drugs).

The second method (*see* Method 2 below) of fingerprinting was based on time series classification using signal processing, and machine learning. A classification method that used supervised learning to create representations of each powdered mixture was employed. When a new series of measurements was obtained, the measurements were compared to the stored class representations to determine the maximum likelihood classification. In some embodiments, the classification procedure built on several component techniques from the field of signal processing, for example, dynamic time warping (DTW) and DTW barycenter averaging (DBA).

The third method (*see* Method 3 below) used machine learning, including deep neural networks, specifically, convolutional neural networks, for image classification.

[0230] In some embodiments, digital fingerprinting can be used to perform attribution, *i.e.*, the process of finding the source of the powdered mixtures (*e.g.*, illicit drugs), or the source of the components in the mixtures. To perform attribution with digital fingerprints, they are, in some embodiments, compared to other fingerprints in a database and the degree of similarity between the different fingerprints are estimated through different types of methods that compare different characteristics of the fingerpint. These methods, in some embodiments, can process and evaluate data about the types of drugs present, quantities of drugs relative to each other, and characteristic particle sizes of each drug. The fingerpints, in some embodiments, can be coupled to other types of data, such as time of seizure and location, enabling the tracking of similar types of fingerprints geographically and over time. This could, for example, be useful to track drug traffick networks to identify the batch, supplier, and, ultimately, the network of distribution channels in the drug trade. The methods described in this Example focus on the analysis of mixtures of powders that contain drugs. However, the method can be used on any powdered mixture (*e.g.*, powdered chemicals, food products, or explosives).

Method 1

[0231] In some embodiments, an experiment generates a series of approximately 100 images, or more, in a time series from a DSLR camera to be processed and analyzed. Each image was processed by first cropping the region of interest (bounded by the lower and side walls of the cuvette and the fluid meniscus at the top), extracting the "intensity," *i.e.*, the value channel in hue, saturation, value ("HSV") color space, calibrating the number of pixels to a linear distance based on a ruler included in the image, and recording the timestamp of the image. After this processing step, each image was an n-by-m matrix of intensity values with known linear spacing (meters) and known time of image capture, where n and m are the height and width of the cropped image in pixels, respectively.

[0232] Following the processing step, each processed image was analyzed to characterize the location of suspended particles, as indicated by pixels with high intensity values due to particles reflecting light. To perform this analysis, the lateral pixels (in the m-direction) were averaged over each row in the matrix representing the image to yield a single value for each vertical pixel location within the image, resulting in an n-by-1 matrix representing the average amount of particles stored at each vertical location (height above the bottom magnet) within the MagLev device (*see* FIG. 15 and FIG. 16). These values were calculated for each image and plotted at sequential points in time to visualize the distribution of particles over time within the device (*see* FIG. 16). The plots were further analyzed by fitting normal distributions to each of the peaks representing equilibrium-point clusters of particles (*see* FIG. 17). These normal distributions were fit directly to the n-by-1 matrix, and the mean intensities in the vertical direction of the MagLev device (described previously), using the fitdist function in MATLAB with the argument 'Normal'. From these distributions, the behavior of the peaks (*e.g.*, vertical translation, sharpening) was quantified over time in terms of the mean value, μ, and the full width at half maximum, FWHM, of each distribution (*see* FIG. 17).

[0233] FIG. 15 shows image processing for determination of light intensity of image at different heights (n-direction) in the cuvette, according to some embodiments. The image shows the separation of lidocaine·HCl (47.5 mg) and caffeine (2.5 mg) that levitated in a paramagnetic solution (0.45 M $Gd(DPM)_3TOPO$ dissolved in a mixture of 23 vol% hexane and 77 vol% of tetrachloroethylene) in a cuvette inside the MagLev device. The image was captured after 20 minutes of separation.

[0234] FIG. 16 shows the equilibration of 5 mg lidocaine and 5 mg caffeine in the MagLev device over time, according to some embodiments. The powders were levitated

separately (left and middle plot) or together (right plot) in a paramagnetic solution of $Gd(DPM)_3TOPO$ (450 mM) in a solvent mixture of 22.9 vol% hexane and 77.1 vol% tetrachloroethylene. The data were obtained from multiple camera images of the levitating powders on a black background acquired over time.

[0235] FIG. 17 shows experimentally measured data and the normal distribution fitted to this data for lidocaine showing the mean, μ_{lido}, and full width at half maximum, $FWHM_{lido}$, of the lidocaine sample at this point in time, according to some embodiments. The left, unlabeled, peak is caffeine.

[0236] In some embodiments, small clouds (a few crystals) of levitating compounds can, in some cases, be difficult to detect when averaging the intensity of the pixels for each m-row, especially if there is significant background noise. In some embodiments, an alternative method of generating intensity profiles over the n-direction is to map the light intensity along the m-position with maximum integrated area under the intensity curve (n versus m). In some embodiments, this method was not used to estimate the amount of substance but, using the intensity curve with the strongest possible signal, was used to detect the presence and position (density) of small clouds of compound. This latter method was used, as demonstrated in FIGS. 19A-B, to generate intensity profiles from the images in FIG. 18 for three different time points as the samples separated in the MagLev device. The intensity profiles in FIG. 19A were generated by manually (by eye in ImageJ) estimating the m-position generating the intensity profile with the strongest signal, however, the profile can be automatically generated from images using a computer code that yield a similar result as in FIGS. 19A-B and FIG. 20. In FIG. 20, the intensity curves for 50 mg samples were compared with different proportions of lidocaine HCl and caffeine.

[0237] In some cases, the images were taken with a set polarizers that were oriented perpendicular to each other, with the first polarizer being placed between the light source and the cuvette, and the second polarizer between the cuvette and the lens of the camera. The polarizers enabled identification of compounds that polarized light, adding another dimension to the fingerprint.

[0238] FIG. 18 shows images of the powdered mixtures (50 mg) of lidocaine·HCl and caffeine, in different proportions, after 20 minutes of separation in the MagLev device, according to some embodiments. The paramagnetic solution consisted of $Gd(DPM)_3TOPO$ (450 mM) dissolved in a solvent mixture of 22.9 vol% hexane and 77.1 vol% tetrachloroethylene. The cuvette was 25 mm tall.

[0239] FIG. 19A shows ImageJ was used to follow the separation of mixtures of lidocaine·HCl and caffeine in different proportions over time in the MagLev device. In each plot, the top curve is 20 minutes, the middle curve is 5 minutes, and the bottom curve is 0 minutes. FIG. 19B shows the paramagnetic solution, which consisted of $Gd(DPM)_3TOPO$ (450 mM) dissolved in a solvent mixture of 22.9 vol% hexane and 77.1 vol% tetrachloroethylene. All profiles shown in FIG. 19A were measured manually with ImageJ in the middle of the cuvette (dashed line in FIG. 19B). The sample in the camera image contained 95 weight% lidocaine·HCl and 5 weight% caffeine, and it was taken after 20 minutes of separation in the MagLev device.

[0240] FIG. 20 shows that ImageJ was used to measure (light intensity – gray value) the separation of mixtures of lidocaine·HCl and caffeine in different proportions in the MagLev device after 20 minutes of separation, according to some embodiments. The paramagnetic solution consisted of $Gd(DPM)_3TOPO$ (450 mM) dissolved in a solvent mixture of 22.9 vol% hexane and 77.1 vol% tetrachloroethylene.

Method 2

[0241] The time series (*i.e.*, the averaged light intensity for each n-row of pixels inside the cuvette) was extracted, using the methods illustrated in FIG. 15, from images, such as the ones exemplified in FIG. 21, and labeled according to their compositions. The images of the separated samples in the cuvette (*see* FIG. 21) were made in an enclosed box that contained the MagLev device and several light sources for controlled illumination. This illumination and imaging of the separated samples in the MagLev device was highly reproducible. The profiles (time series) for the different samples possessed distinct features (*see* FIG. 23, FIG. 24, and FIG. 25). For example, lidocaine·HCl had a distinctly different profile than caffeine. In some embodiments, a major challenge in discriminating between lidocaine and caffeine profiles is their variations in the time and measurement domain. For example, lidocaine HCl samples may vary in their compositions resulting in measurement signals that are stretched or compressed (vary over time). To classify the measurement profiles, these variations must be accounted for.

[0242] FIG. 21 shows images of levitating samples of powder in the MagLev device, according to some embodiments. The powders (each cuvette contained 50 mg of powder) levitated in a paramagnetic solution (0.45 M $Gd(DPM)_3TOPO$ dissolved in tetrachloroethylene) in a cuvette inside the MagLev device. The image was captured after 20 minutes of separation. These images were captured using the box in FIG. 22.

Method 3

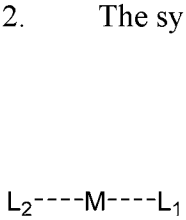
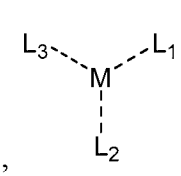
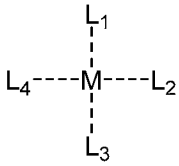
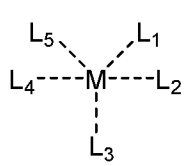
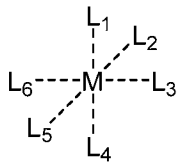
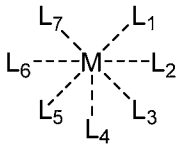
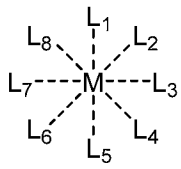
[0243] Several pathways within machine learning were investigated, including deep neural networks, specifically, convolutional neural networks, for image classification. Rather than processing the images and converting them to spatial sequences, entire sets of images were inserted to train the classifiers (one classifier for each mixture of powders).

CLAIMS

1. A magnetic levitation system comprising:

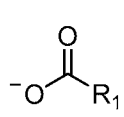
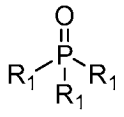
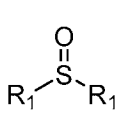
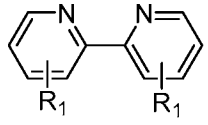
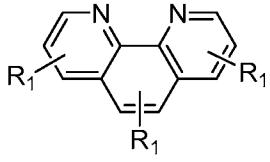
a first and second magnets having surfaces of their like-poles facing each other; and

a container disposed between the first and second magnets' like poles and containing a solution comprising a paramagnetic complex in a non-aqueous solvent; wherein the paramagnetic complex comprises a paramagnetic metal and at least one ligand that coordinates to the paramagnetic metal via electron donation.

2. The system of claim 1, wherein the paramagnetic complex has the structure  ,  ,  ,  ,  ,  , or  , wherein M is a paramagnetic metal and L_1, L_2, L_3, L_4, L_5, L_6, L_7, and L_8 are ligands that coordinate to the paramagnetic metal via electron donation.

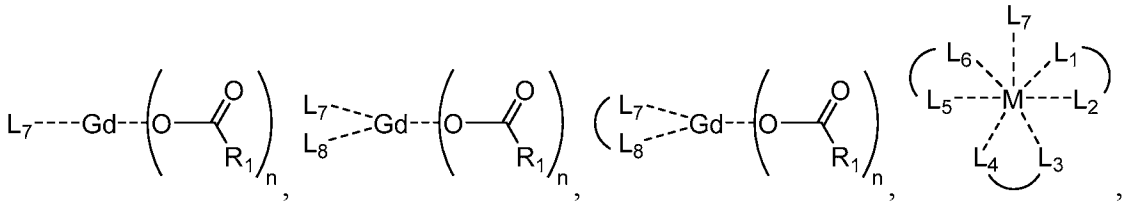
3. The system of claims 1 or 2, wherein L_1, L_2, L_3, L_4, L_5, L_6, L_7, and L_8 are independently selected from the group consisting of substituted or unsubstituted phosphine oxides, oxazoles, imidazoles, pyridines, diamines, bipyridines, phenanthrolines, diketonates, malonamides, malonates, β-ketoesters, β-ketoamides, carboxylates, dicarboxylates, and ethylenediaminetetraacetic acid.

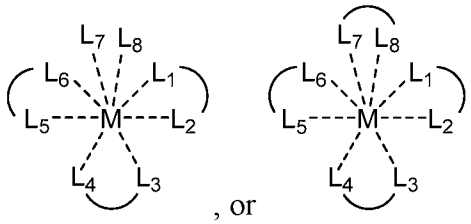
4. The system of any one of claims 1-3, wherein two or more of L_1, L_2, L_3, L_4, L_5, L_6, L_7, and L_8 are covalently bonded to a substituent group consisting of 1-20 carbon atoms.

5. The system of any one of claims 1-4, wherein at least one of L_1, L_2, L_3, L_4, L_5, L_6, L_7, and L_8 comprises  ,  ,  ,  , or  , wherein each occurrence R_1 is independently H, (C_1-C_{20})alkyl, (C_2-C_{20})alkenyl, (C_2-C_{20})alkynyl, (C_3-C_{10})cycloalkyl, (C_6-C_{10})aryl, or (C_6-C_{10})heteroaryl, each of which is optionally substituted with one or more substituents selected from the group consisting of

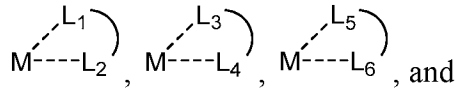
halogen, R^a, OR^a, NR^aR^b, COR^a, CO_2R^a, or $CONR^aR^b$; and where R^a and R^b are independently selected from the group consisting of hydrogen and $(C_1\text{-}C_6)$alkyl.

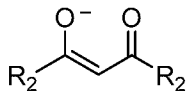
6. The system of any one of claims 1-5, wherein the paramagnetic complex has the structure



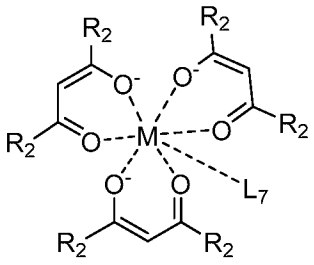


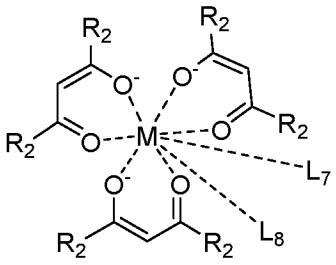
, or , wherein n is an integer from 1-7 and wherein " " denotes the group consisting of 1-20 carbon atoms.

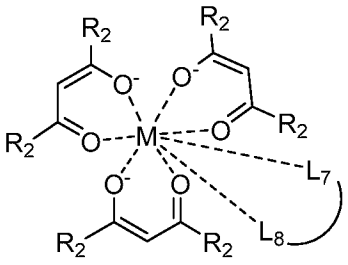
7. The system of claim 6, wherein 

are independently selected from the group consisting of 2,2'-dipyridyl, optionally substituted with one or more R_1, 1,10-phenanthrenyl, optionally substituted with one or more R_1, and 

, wherein each occurrence of R_2 is independently H, $(C_1\text{-}C_{20})$alkyl, $(C_2\text{-}C_{20})$alkenyl, $(C_2\text{-}C_{20})$alkynyl, $(C_3\text{-}C_{10})$cycloalkyl, $(C_6\text{-}C_{10})$aryl, or $(C_6\text{-}C_{10})$heteroaryl, each of which is optionally substituted with one or more substituents selected from the group consisting of halogen, R^a, OR^a, NR^aR^b, COR^a, CO_2R^a, or $CONR^aR^b$; and where R^a and R^b are independently selected from the group consisting of hydrogen and $(C_1\text{-}C_6)$alkyl.

8. The system of any one of claims 1-7, wherein the paramagnetic complex has the structure, 

, 

, or 

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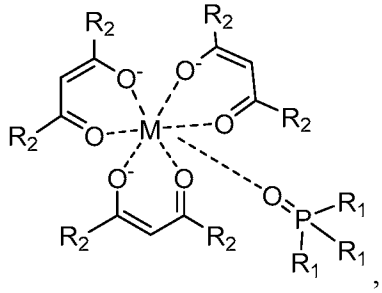
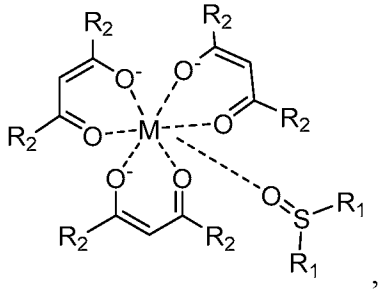
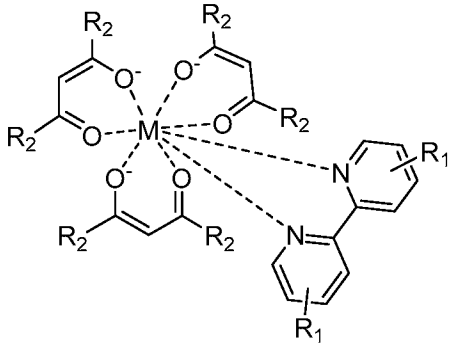
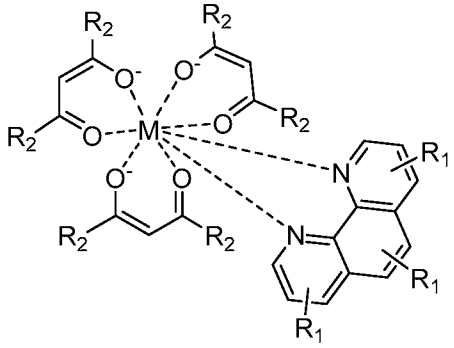
9. The system of any one of claims 1-8, wherein the paramagnetic complex has the structure  ,  ,  , or  .

10. The system of any one of claims 5-9, wherein each occurrence of R_1 and R_2 is independently $(C_1\text{-}C_{10})$alkyl or $(C_6\text{-}C_{10})$aryl.

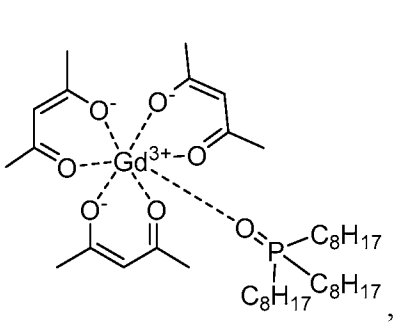
11. The system of any one of claims 5-10, wherein each occurrence of R_1 and R_2 is independently methyl, ethyl, propyl, butyl, pentyl, hexyl, heptyl, octyl, nonyl, decyl, phenyl, or isomers thereof.

12. The system of any one of claims 5-11, wherein each occurrence of R_1 and R_2 is independently methyl, butyl, tert-butyl, octyl, or phenyl.

13. The system of any one of claims 1-12, wherein M is selected from the group consisting of scandium, titanium, vanadium, chromium, manganese, iron, cobalt, nickel, cerium, praseodymium, neodymium, europium, gadolinium, terbium, dysprosium, copper, holmium, erbium, thulium, and lanthanum.

14. The system of any one of claims 1-13, wherein M is gadolinium.

15. The system of any one of claims 1-14, wherein the paramagnetic complex is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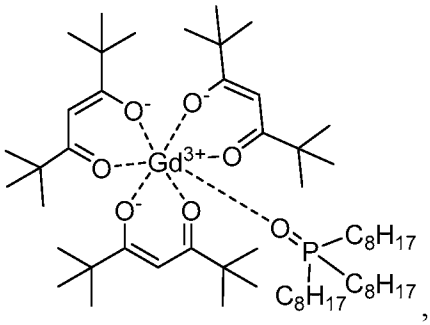
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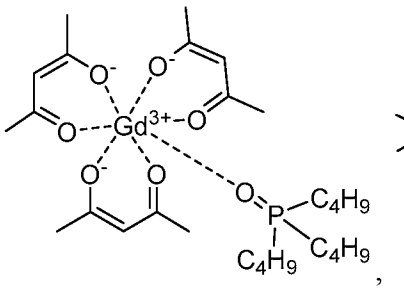
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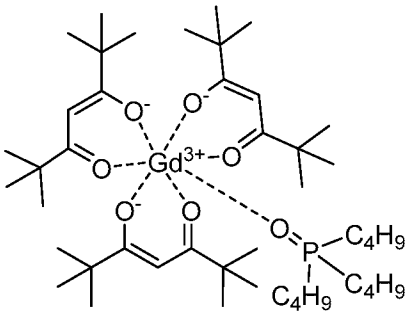
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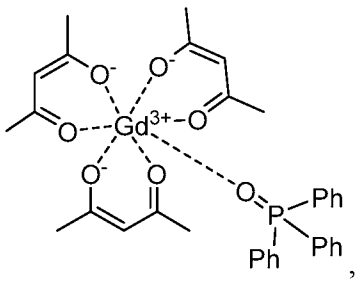
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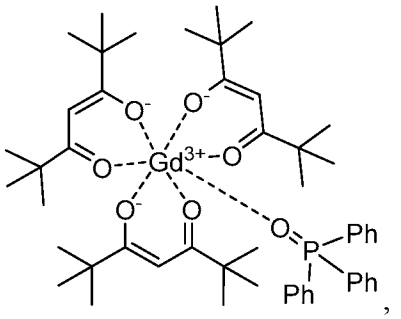
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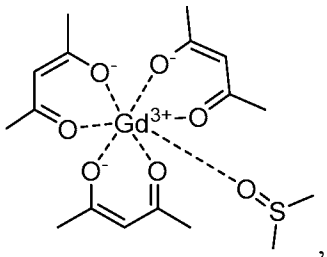
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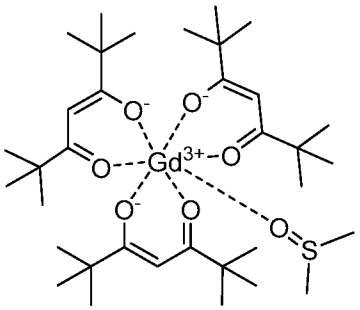
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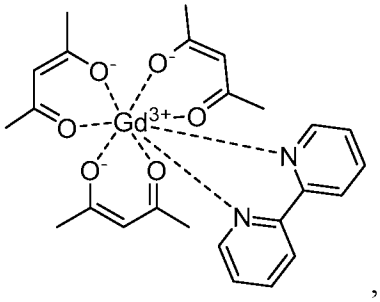
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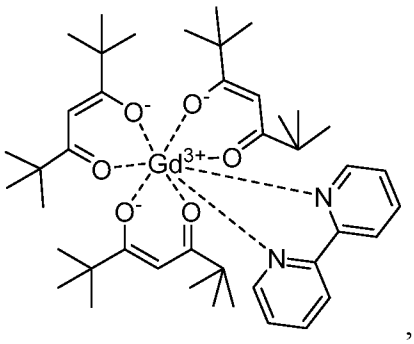
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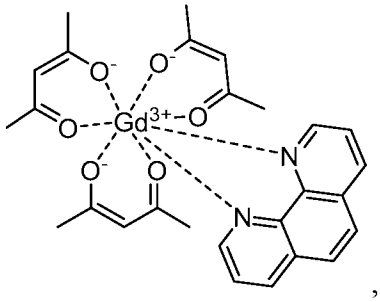
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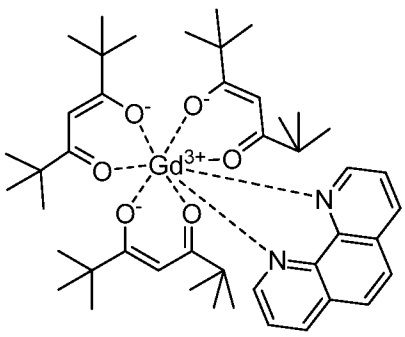
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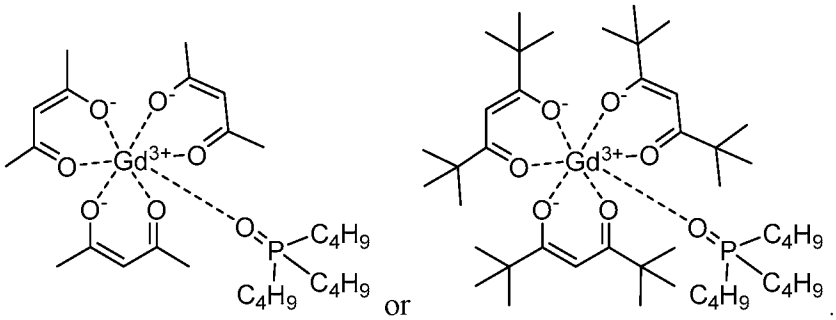
16. The system of any one of claims 1-15, wherein the paramagnetic complex is



or

17. The system of any one of claims 1-16, wherein the solvent is selected from the group consisting of acyclic and cyclic hydrocarbons, acyclic and cyclic halo- or per-halo hydrocarbons, aromatic hydrocarbons, acyclic and cyclic ethers, and acyclic and cyclic aldehydes, ketones, esters, amides, sulfides, sulfoxides, and sulfones, and a combination thereof.

18. The system of any one of claims 1-17, wherein the solvent is pentane, hexane, heptane, octane, nonane, decane, undecane, dodecane, tetrachloroethylene, carbon tetrachloride, dichloromethane, trichloromethane, diethyl ether, tetrahydrofuran, ethyl acetate, butyl acetate, or a combination thereof.

19. The system of claim 18, wherein the solvent is hexane, tetrachloroethylene, or a combination thereof.

20. The system of claims 18 or 19, wherein the solvent is tetrachloroethylene.

21. The system of any one of claims 1-20, wherein the system further comprises a camera, or a light source to illuminate the container, or both.

22. The system of any one of claims 1-21, wherein the container is an open or closed vessel capable of holding the solution.

23. The system of any one of claims 1-22, wherein the container is made from a glass, a plastic, a polymer, a ceramic, one or more plant-based fibers in a polymer matrix, one or more plant-based fibers in a ceramic matrix, an aerogel, a gel comprising polar or apolar solvents, a non-ferromagnetic, non-ferrimagnetic, or non-paramagnetic metal, or a combination thereof.

24. The system of any one of claims 1-23, wherein the container is a cuvette, jar, test tube, centrifuge tube, or capillary tube.

25. The system of any one of claims 1-25, wherein the container is a cuvette.

26. The system of any one of claims 1-25, wherein the first and second magnets are each independently selected from the group consisting of a permanent magnet, an electromagnet, and a superconducting magnet.

27. The system of any one of claims 1-26, wherein the first and second magnets are permanent magnets.

28. The system of any one of claims 1-27, wherein the first and second magnets are each independently neodymium magnets, samarium-cobalt magnets, ferrite magnets, or Alnico magnets.

29. The system of any one of claims 1-28, wherein the first and second magnets are each independently shaped as a block, a cylinder, a sphere, a disc, or a ring.

30. A method of analyzing a sample comprising one or more solid compounds, the method comprising:

(a) providing the magnetic levitation system of any one of claims 1-29;

(b) depositing the sample in the solution; and

(c) allowing each of the solid compounds in the sample to migrate to a position in the container indicative of its density.

31. The method of claim 30, further comprising

(d) analyzing one or more of the solid compounds to determine or confirm its identity.

32. The method of claim 31, wherein step (d) comprises positioning the container such that one or more of the compounds contact the wall of the container and analyzing said compound(s) through the wall of the container using a spectrometer.

33. The method of claims 31 or 32, wherein step (d) comprises removing the one or more solid compounds from the container.

34. The method of claim 33, wherein the one or more solid compounds are removed using a pipette, a siphon, a spoon, a spatula, or a small basket.

35. The method of any one of claims 31-34, wherein the analysis comprises a technique selected from the group consisting of Fourier transform infrared spectroscopy with attenuated total reflectance, mass spectrometry, nuclear magnetic resonance spectroscopy, Raman spectroscopy, X-ray diffractometry, capillary electrophoresis, gas chromatography, ion-mobility spectrometry, liquid chromatography, microcrystalline tests, supercritical fluid chromatography, thin layer chromatography, ultraviolet/visible spectroscopy, microscopy, visual examination, colorimetric tests, fluorescence spectroscopy, immunoassays, melting point analysis, pharmaceutical package inserts, and combinations thereof.

36. The method of claim 35, wherein the technique comprises a portable or handheld device.

37. The method of claim 35, wherein the technique is Fourier transform infrared spectroscopy with attenuated total reflectance, Raman spectroscopy, mass spectrometry, X-ray diffractometry, a colorimetric test, or a combination thereof.

38. The method of any one of claims 35-37, wherein the Raman spectroscopy is conducted using a portable or handheld device.

39. The method of any one of claims 30-38, wherein the sample is a crystalline or amorphous sample.

40. The method of any one of claims 30-39, wherein the sample comprises one or more controlled substances, adulterants, diluents, or a combination thereof.

41. The method of any one of claims 30-40, wherein the sample comprises fentanyl, acetyl fentanyl, benzyl fentanyl, carfentanyl, cocaine, heroin, oxycodone, methamphetamine, cannabinoids, lysergic acid diethylamide, methaqualone, methadone, hydromorphone, Ritalin, Adderall, peyote, 3,4-methylenedioxymethamphetamine, acetaminophen, caffeine, diltiazem, dipyrone/metamizole, lidocaine, hydroxyzine, levamisole, papaverine, procaine, phenacetin, dimethyl sulfone, D-fructose, D-glucose, α-lactose, D-mannitol, sodium carbonate, starch, including potato starch, sucrose, talc, quinine, butylated hydroxytoluene, hypromellose, polyethylene glycol, polyethylene oxide, magnesium stearate, titanium dioxide, an isomer thereof, a salt thereof, a combination thereof.

42. The method of claim 41, wherein the salt is a sodium, aluminum, potassium, calcium, hydrochloride, citrate, nitrate, sulfate, acetate phosphate, diphosphate, maleate, mesylate, tartrate, or gluconate salt.

43. The method of claim 42, wherein the salt is a hydrochloride salt.

44. The method of any one of claims 30-43, wherein the sample comprises a salt of fentanyl or caffeine.

45. The method of any one of claims 30-44, wherein the one or more compounds are present in the sample between 0.01 and 100 weight percent.

46. The method of any one of claims 30-45, wherein the one or more compounds are present in the sample between 0.01 and 10 weight percent.

47. The method of any one of claims 30-46, further comprising:

(e) generating a profile of the position of the one or more compounds relative to the container; and

(f) generating a database comprising a plurality of profiles, each of which corresponds to a known solid compound or a known mixture of solid compounds.

48. The method of any one of claim 47, wherein the profile of the sample and the profiles of the database are determined at a plurality of time points after the sample is deposited in the solution in step (b).

49. The method of claims 47 or 48, further comprising:

(g) comparing the profile of the sample to the profiles in the database.

50. The method of claim 49, wherein step (g) further comprises determining the identity of the compound based on the comparison.

51. The method of claims 49 or 50, wherein step (g) further comprises:

using a computer to calculate the distances between the generated profile of the sample and the profiles in the database to identify a profile in the database within a minimum distance to the generated profile; wherein the distance is a Euclidian or Mahalanobis distance.

52. The method of any one of claims 49-51, wherein the profile in the database further comprises the source of the known solid compound or the known mixture of solid compounds and step (g) further comprises determining the source of the sample.

53. The method of any one of claims 49-52, wherein step (g) further comprises determining the particle size or the mixture of particle sizes of the compound.

54. The method of any one of claims 49-53, wherein the profile in the database further includes a source of the compound and step (g) further comprises determining the source of the sample.

55. The method of any one of claims 30-54, wherein the method comprises obtaining and processing spectroscopic, spectrometric, chromatographic, colorimetric, microscopic, photographic, or visual signals of the one or more solid compounds at a position in the container before, at predetermined times during migration, and after migration.

56. The method of any one of claims 30-55, wherein the method comprises obtaining and processing microscopic or photographic images of the one or more solid compounds at a position in the container before, at predetermined times during migration, and after migration.

57. The method of claim 56, wherein the light intensity of one or more portions of the image before, at predetermined times during migration, and after migration is measured.

58. The method of any one of claims 55-57, wherein the signals, images, or light intensity measurements of the container are processed by using dynamic time warping, barycenter averaging, machine learning, or a combination thereof.

59. The method of claim 58, wherein the machine learning comprises deep neural networks.

60. The method of claim 59, wherein the machine learning comprises supervised deep learning to train a convolutional neural network on hundreds-to-thousands of signals, images, or light intensity measurements.

61. The method of claim 60, wherein the analysis of unknown mixtures comprises inputting one or more generated signals, images, or light intensity measurements into the trained convolutional neural network and obtaining an output of the identity of the mixture.

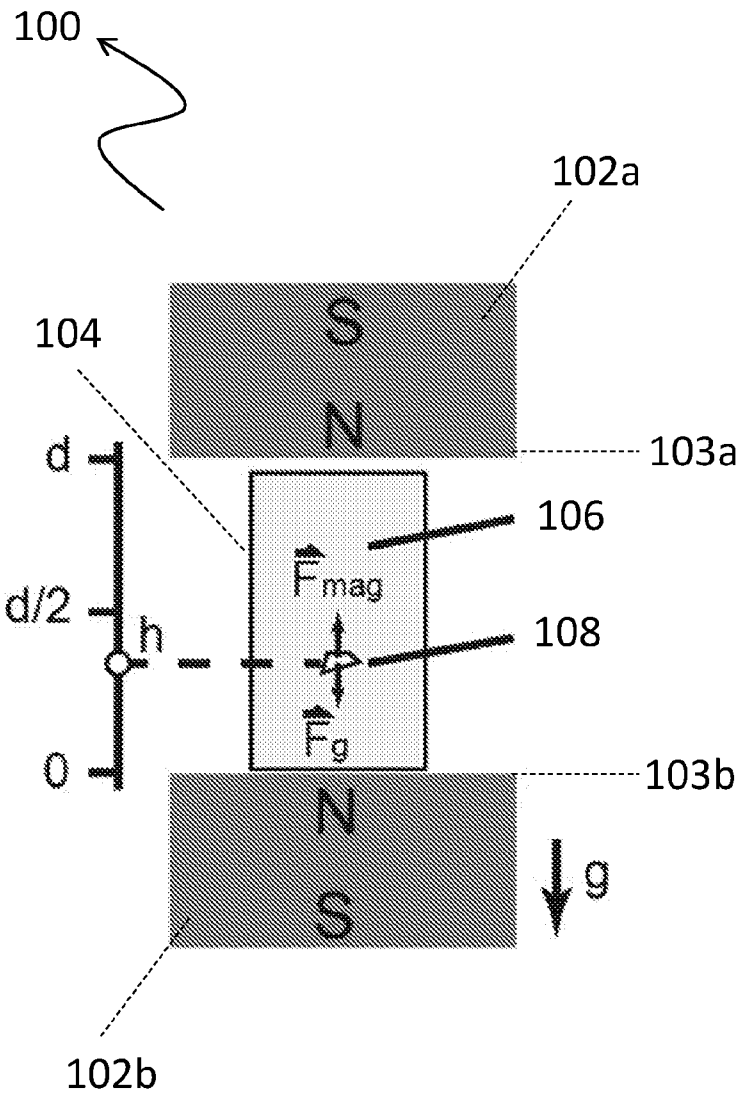

100
102a
S
N
104
103a
d
106
$\vec{F}_{mag}$
d/2
h
108
$\vec{F}_g$
0
103b
N
S
g
102b

FIG. 1A

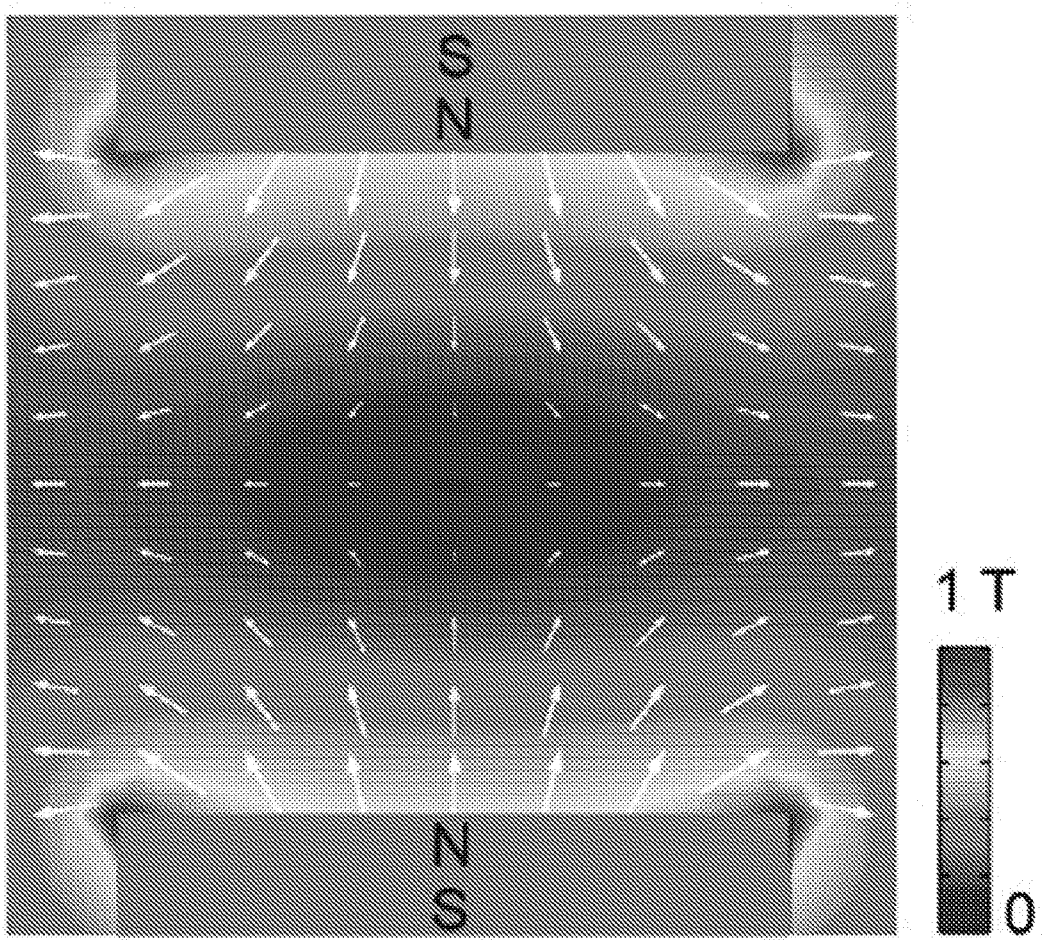


FIG. 1B

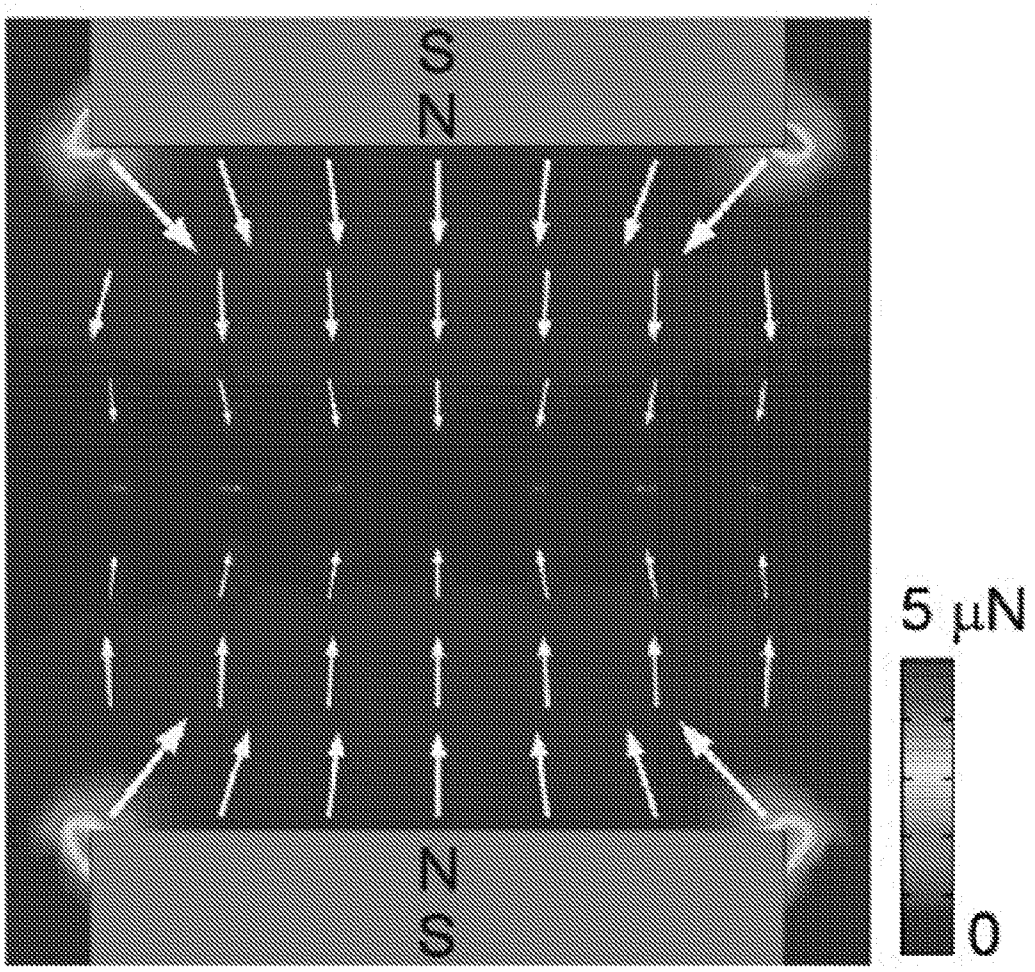


FIG. 1C

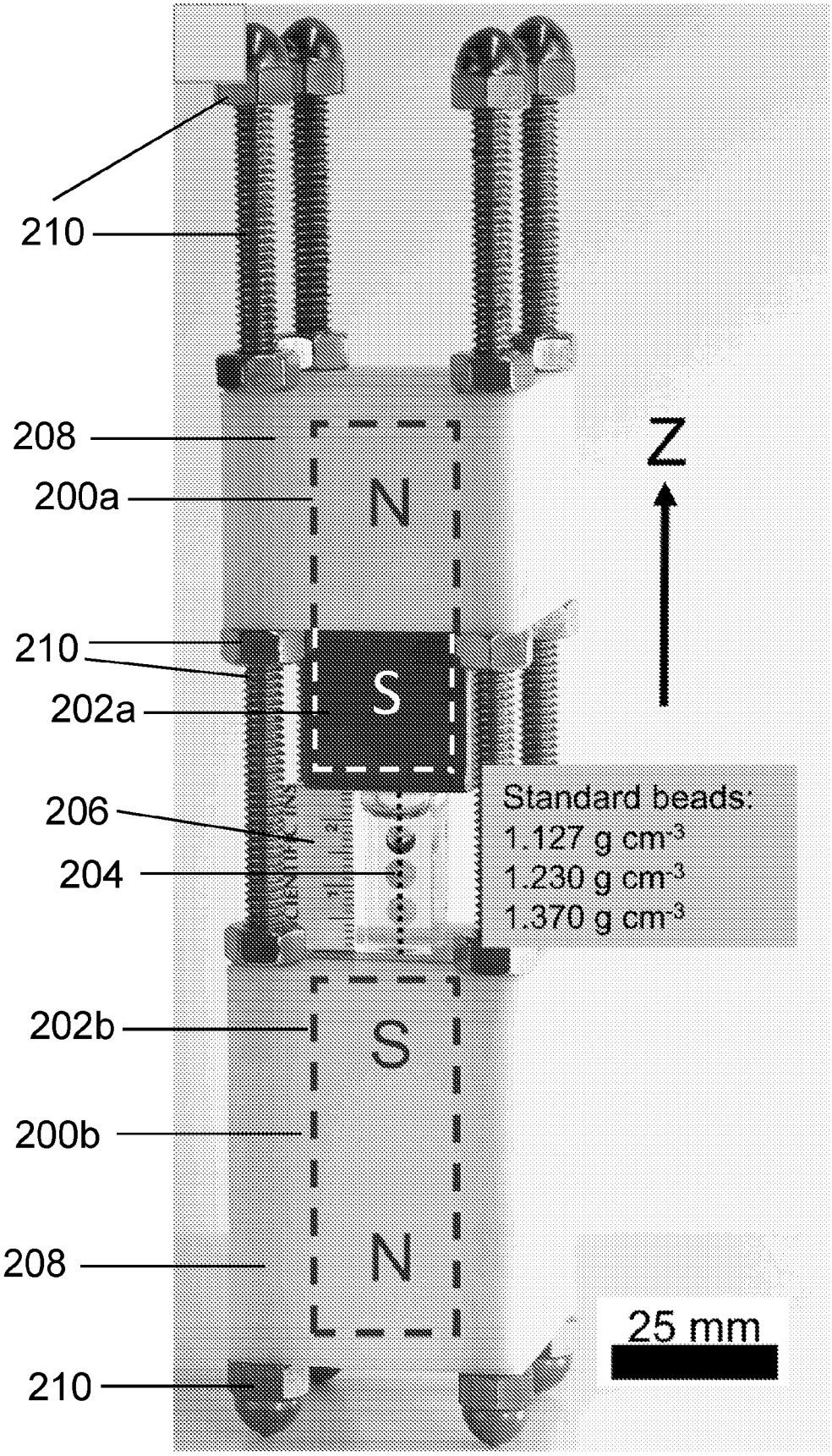

210
208
200a
210
202a
206
204
202b
200b
208
210
N
S
S
N
Z
Standard beads:
1.127 g cm-3
1.230 g cm-3
1.370 g cm-3
25 mm

FIG. 2A

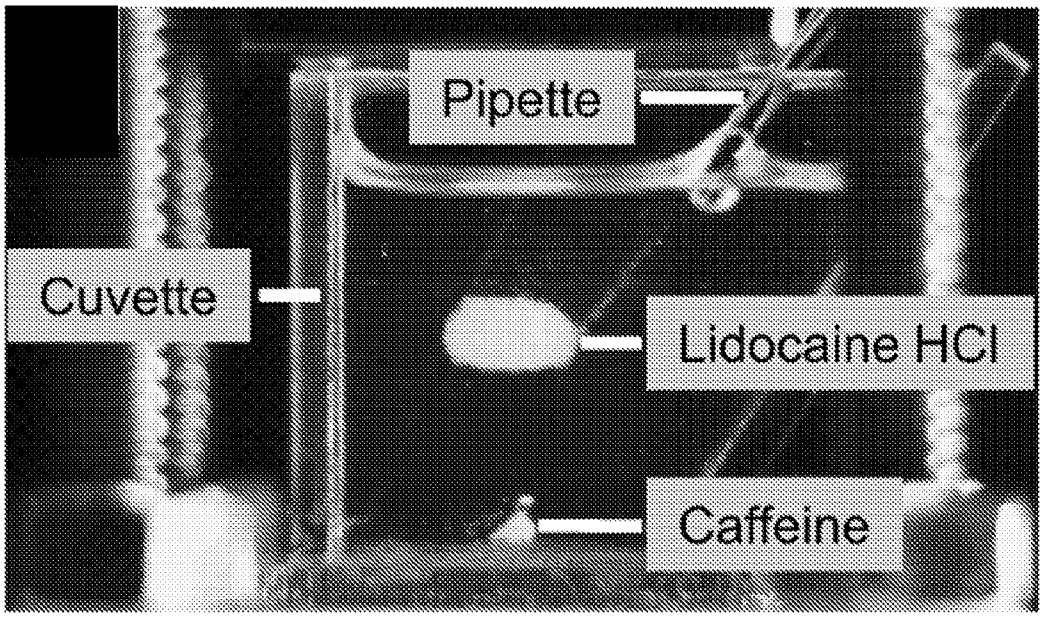


FIG. 2B

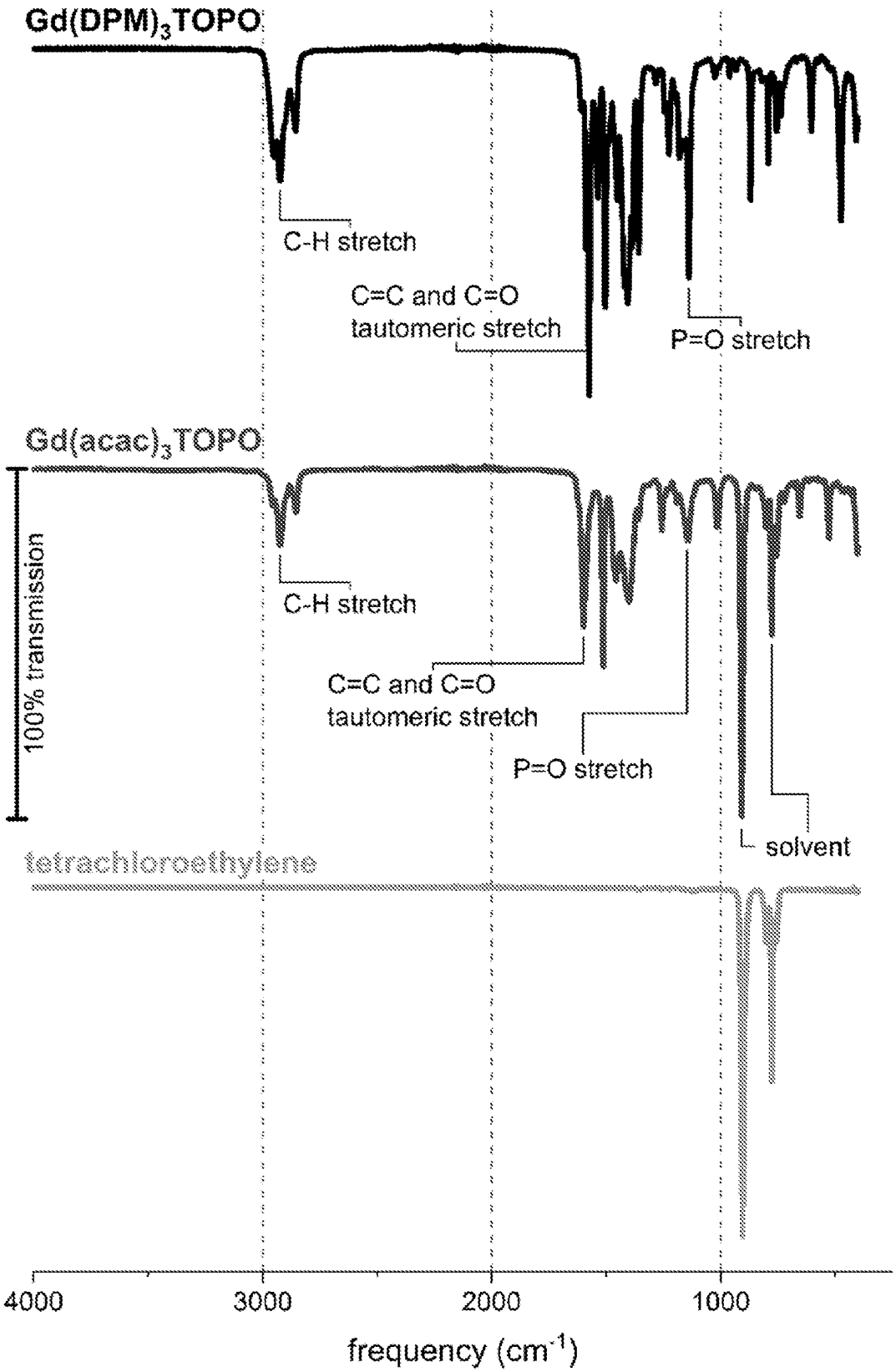

Gd(DPM)3TOPO
C-H stretch
C=C and C=O
tautomeric stretch
P=O stretch
Gd(acac)3TOPO
100% transmission
C-H stretch
C=C and C=O
tautomeric stretch
P=O stretch
solvent
tetrachloroethylene
4000
3000
2000
1000
frequency (cm-1)

FIG. 3

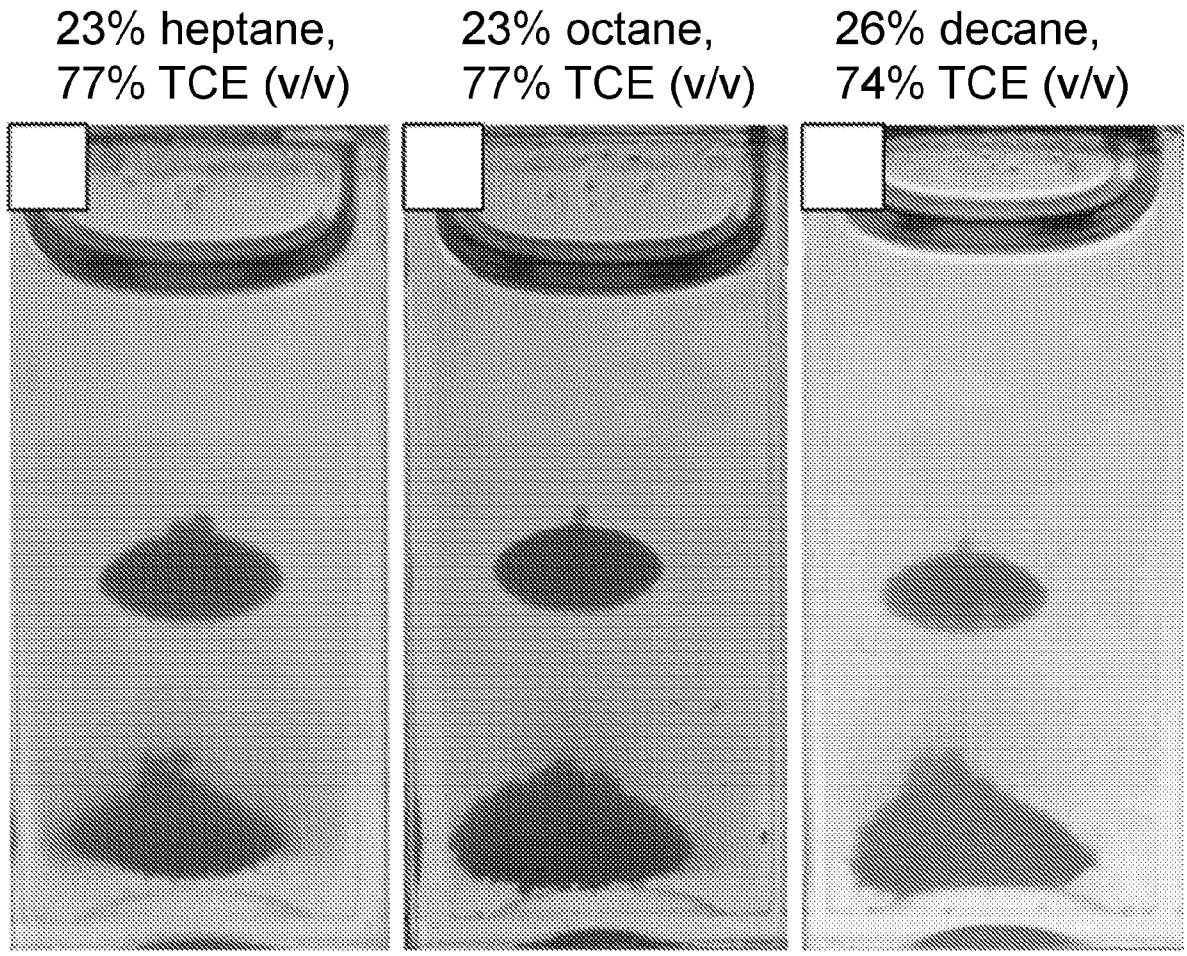


FIG. 4

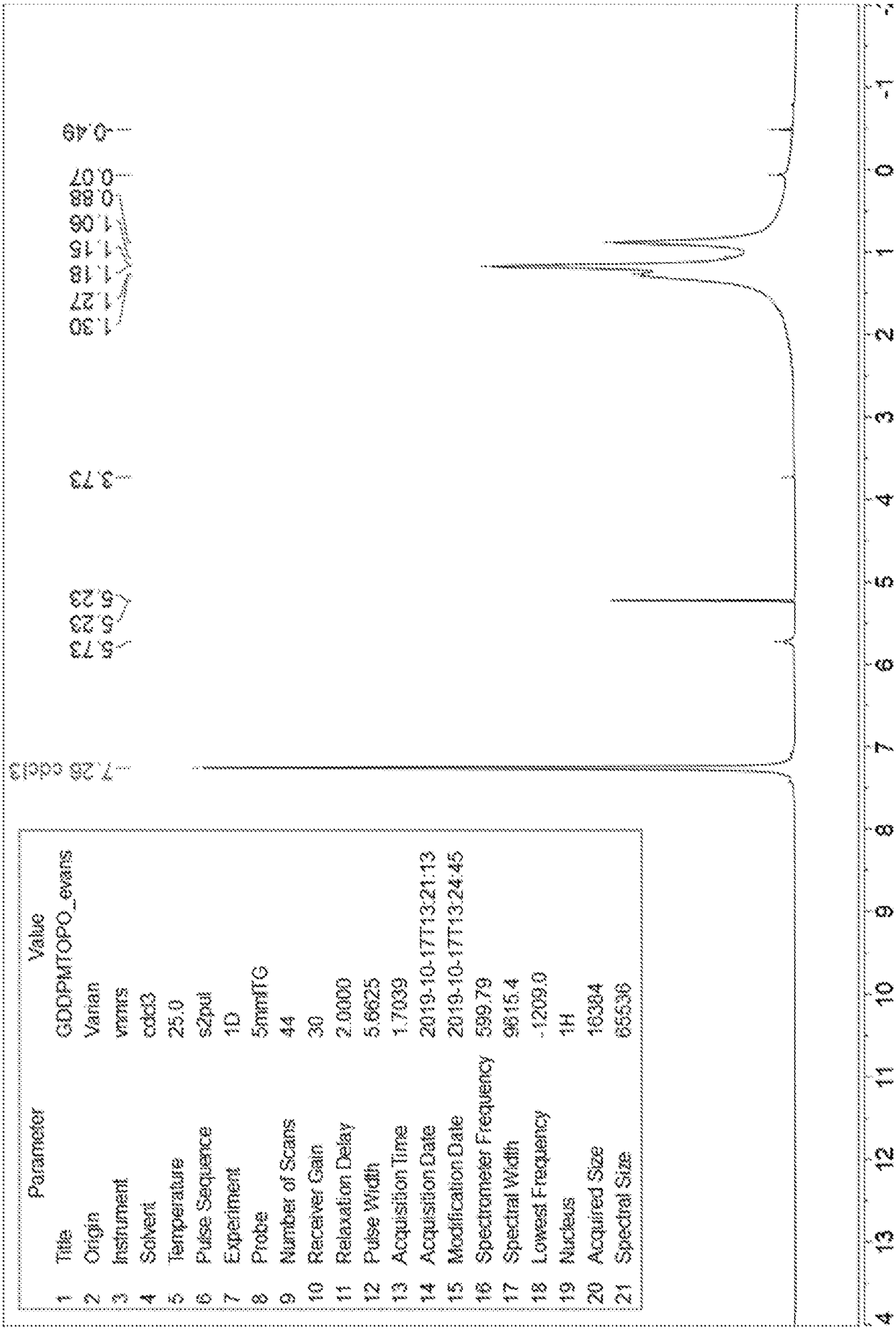

Parameter Value
1 Title GDDPMTOPO_evans
2 Origin Varian
3 Instrument vnmrs
4 Solvent cdcl3
5 Temperature 25.0
6 Pulse Sequence s2pul
7 Experiment 1D
8 Probe 5mmTG
9 Number of Scans 44
10 Receiver Gain 30
11 Relaxation Delay 2.0000
12 Pulse Width 5.6625
13 Acquisition Time 1.7039
14 Acquisition Date 2019-10-17T13:21:13
15 Modification Date 2019-10-17T13:24:45
16 Spectrometer Frequency 599.79
17 Spectral Width 9615.4
18 Lowest Frequency -1209.0
19 Nucleus 1H
20 Acquired Size 16384
21 Spectral Size 65536
7.26 cdcl3
5.73
5.23
5.23
3.73
1.30
1.27
1.18
1.15
1.06
0.88
0.07
-0.46
f1 (ppm)

FIG. 5

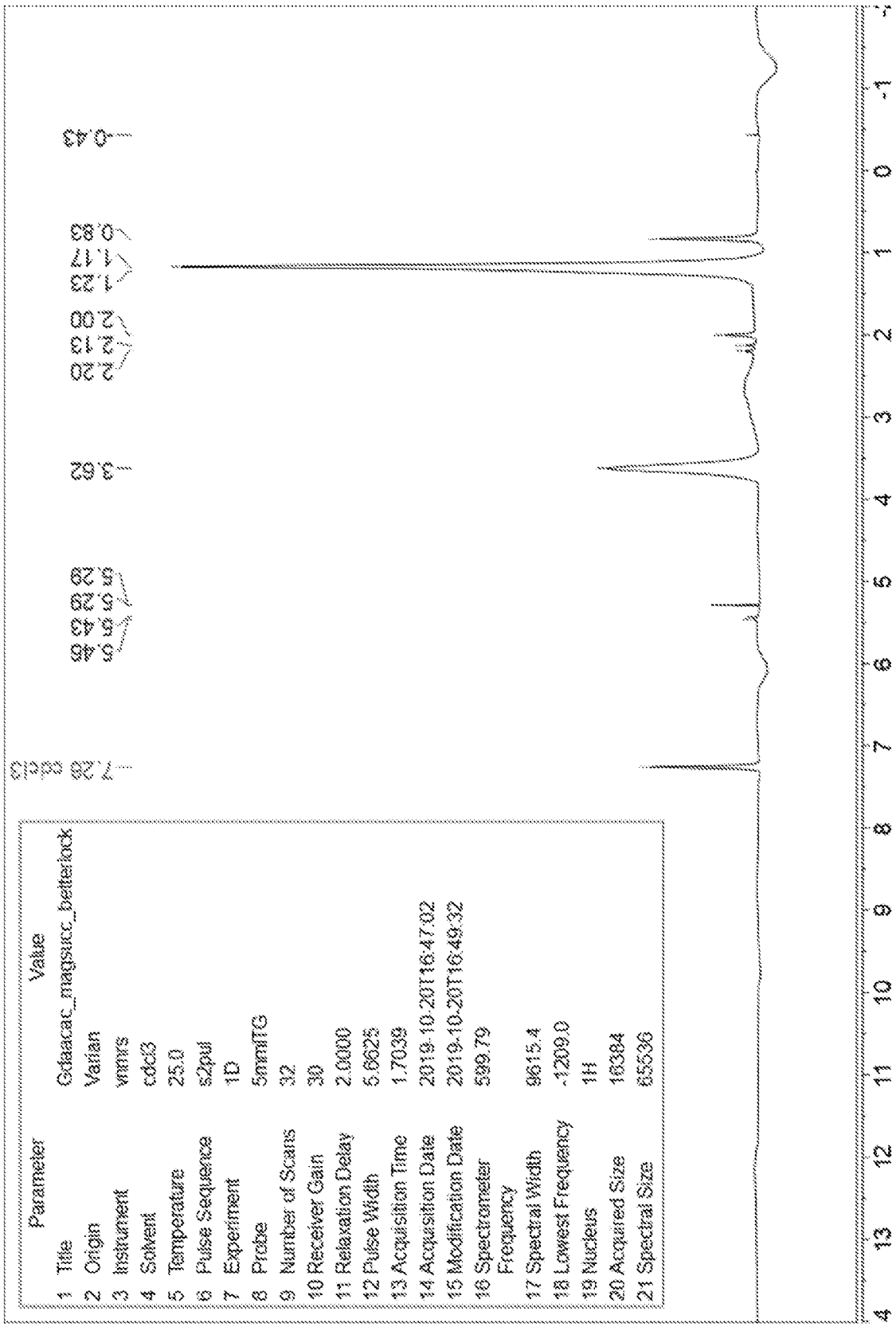

Parameter
Value
1 Title
Gdaacac_magsacc_betterlock
2 Origin
Varian
3 Instrument
vnmrs
4 Solvent
cdcl3
5 Temperature
25.0
6 Pulse Sequence
s2pul
7 Experiment
1D
8 Probe
5mmTG
9 Number of Scans
32
10 Receiver Gain
30
11 Relaxation Delay
2.0000
12 Pulse Width
5.6625
13 Acquisition Time
1.7039
14 Acquisition Date
2019-10-20T16:47:02
15 Modification Date
2019-10-20T16:49:32
16 Spectrometer Frequency
599.79
17 Spectral Width
9615.4
18 Lowest Frequency
-1209.0
19 Nucleus
1H
20 Acquired Size
16384
21 Spectral Size
65536
f1 (ppm)

FIG. 6

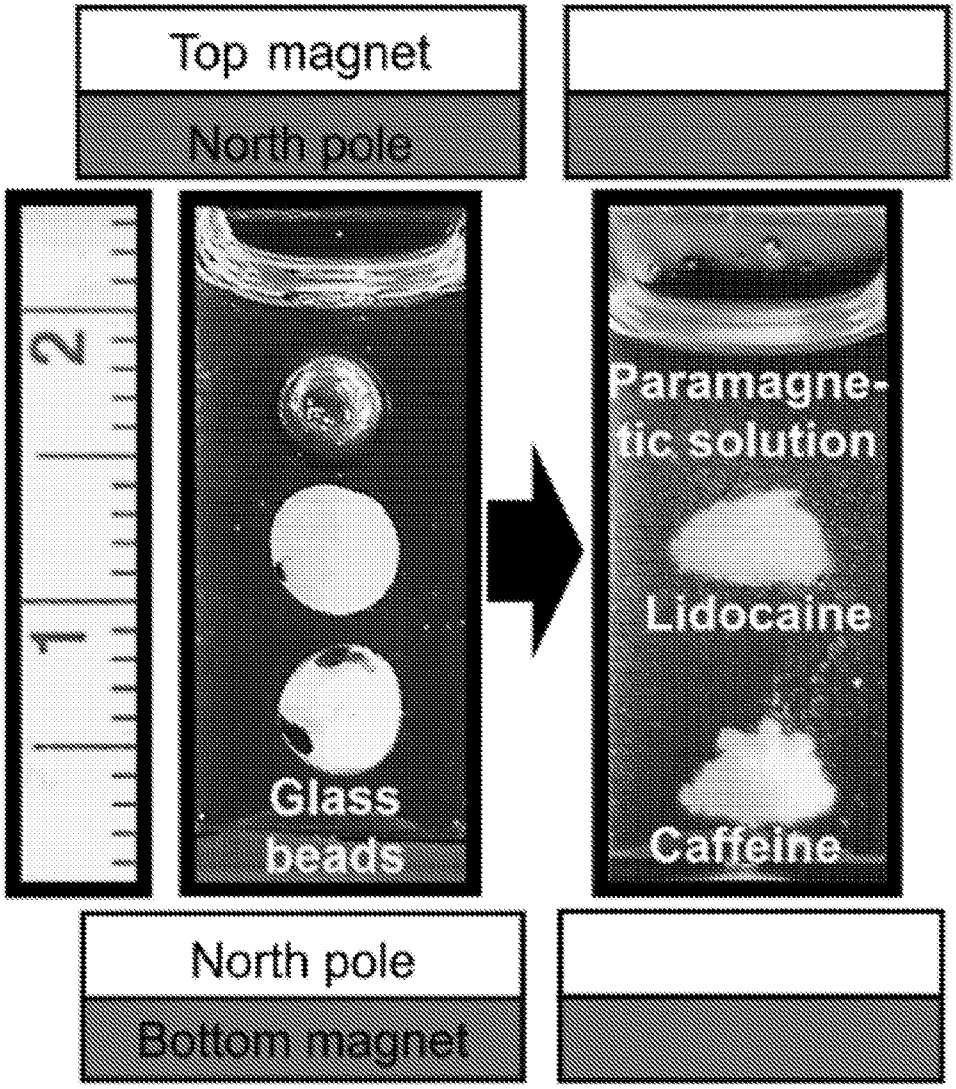

Top magnet
North pole
2
1
Glass beads
Paramagne-tic solution
Lidocaine
Caffeine
North pole
Bottom magnet

FIG. 7A

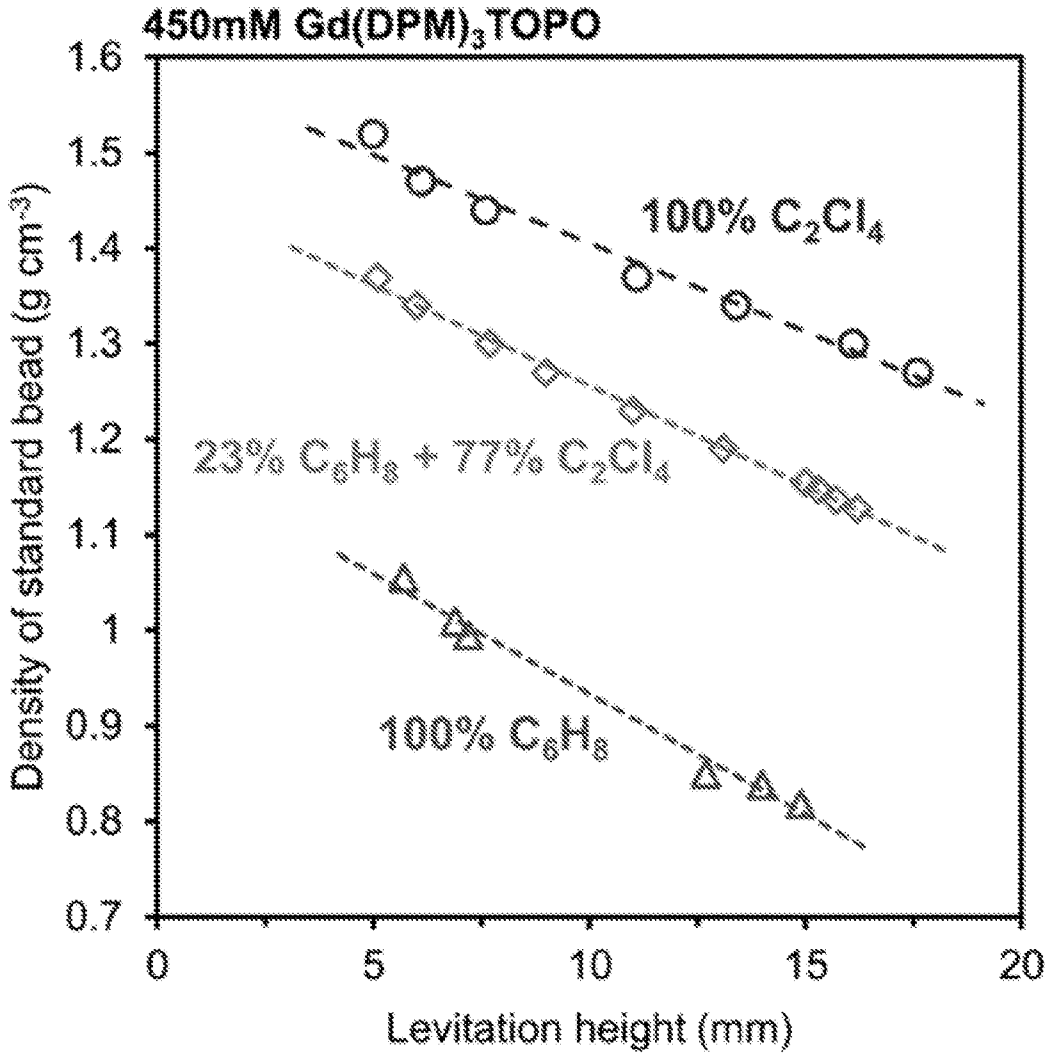

450mM Gd(DPM)3TOPO
Density of standard bead (g cm-3)
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
100% C2Cl4
23% C6H8 + 77% C2Cl4
100% C6H8
0
5
10
15
20
Levitation height (mm)

FIG. 7B

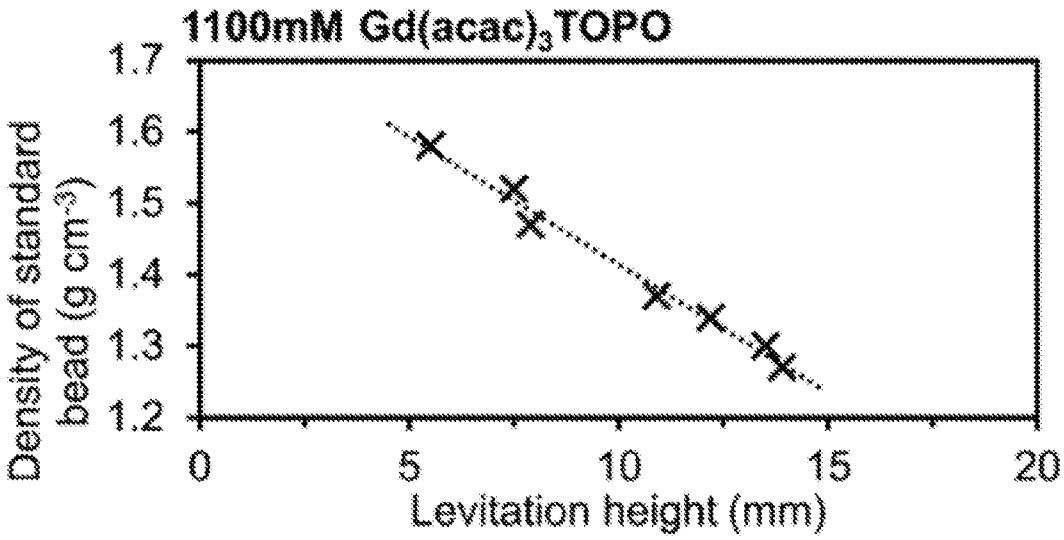

1100mM Gd(acac)3TOPO
Density of standard bead (g cm-3)
1.7
1.6
1.5
1.4
1.3
1.2
0
5
10
15
20
Levitation height (mm)

FIG. 7C

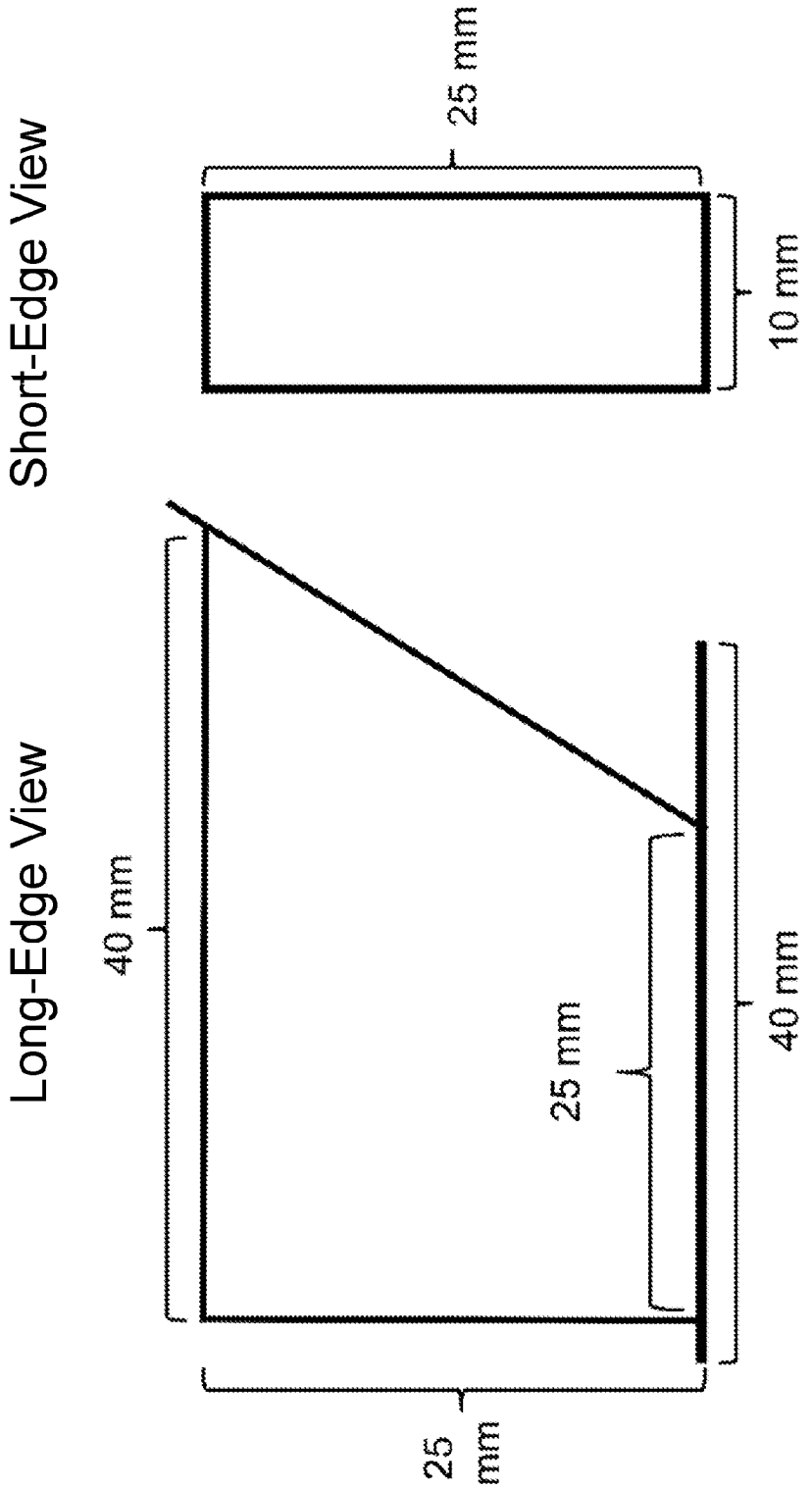


FIG. 8

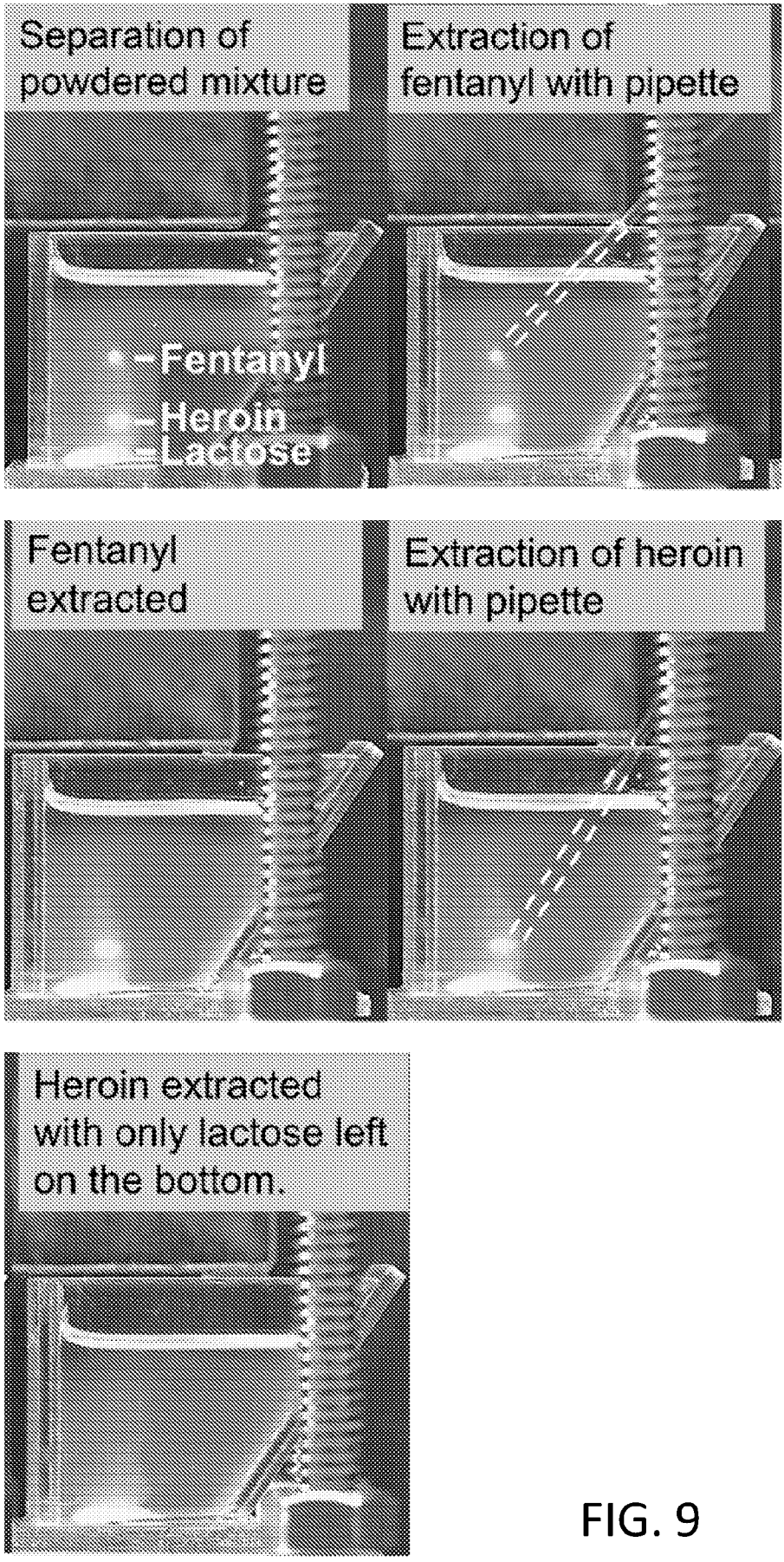

Separation of powdered mixture
Extraction of fentanyl with pipette
Fentanyl
Heroin
Lactose
Fentanyl extracted
Extraction of heroin with pipette
Heroin extracted with only lactose left on the bottom.

FIG. 9

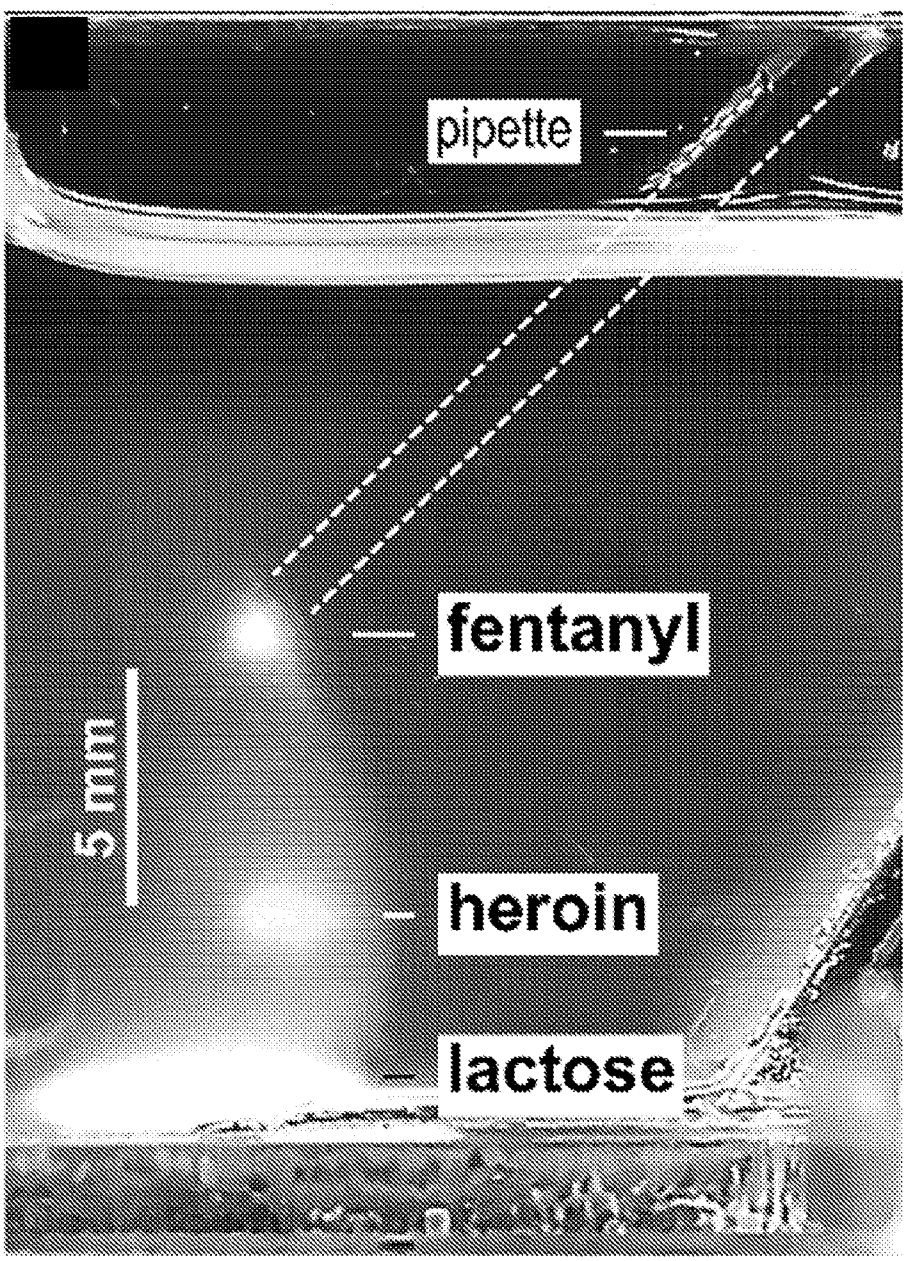


FIG. 10A

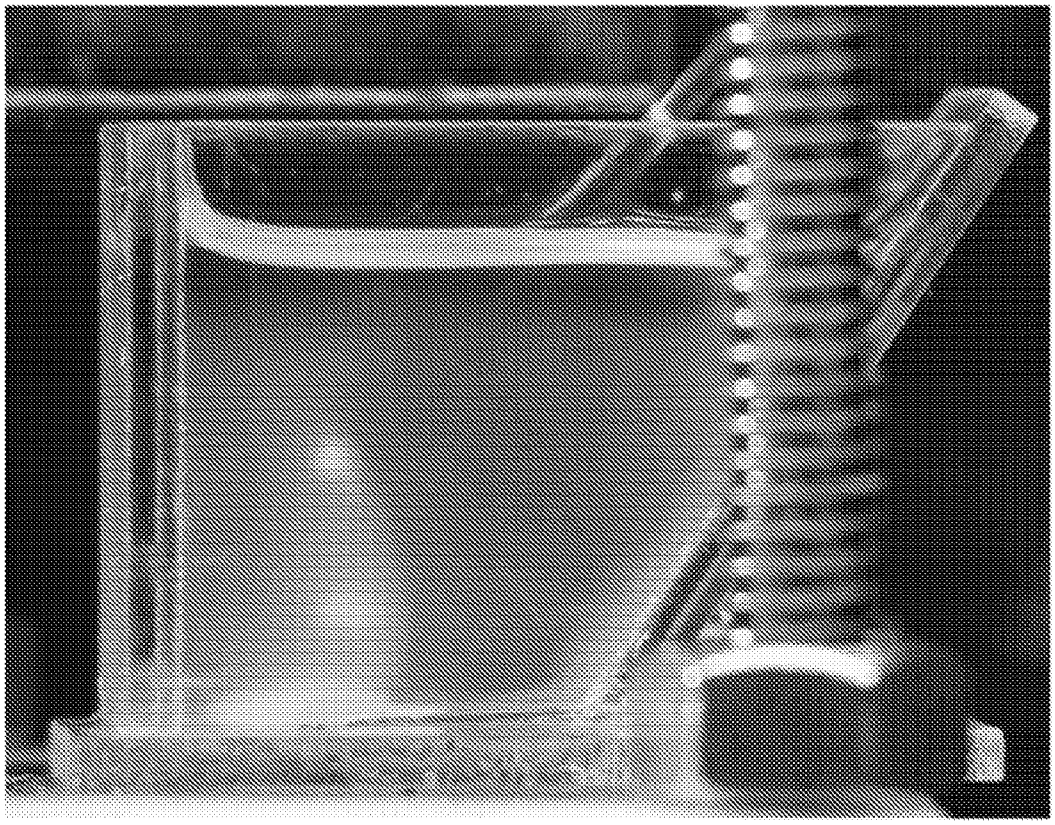


FIG. 10B

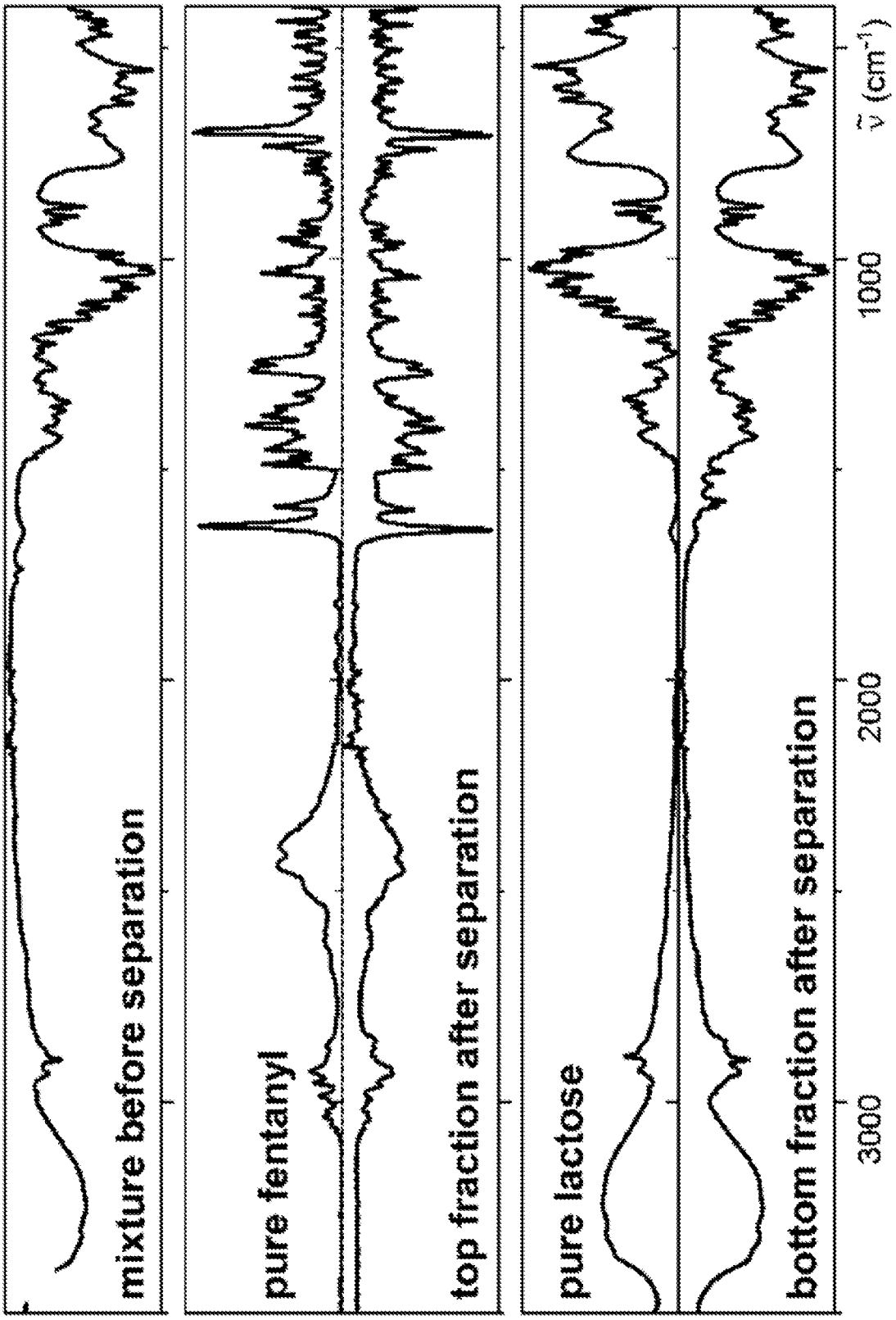

mixture before separation
pure fentanyl
top fraction after separation
pure lactose
bottom fraction after separation
3000
2000
1000
$\tilde{\nu}$ (cm^{-1})

FIG. 10C

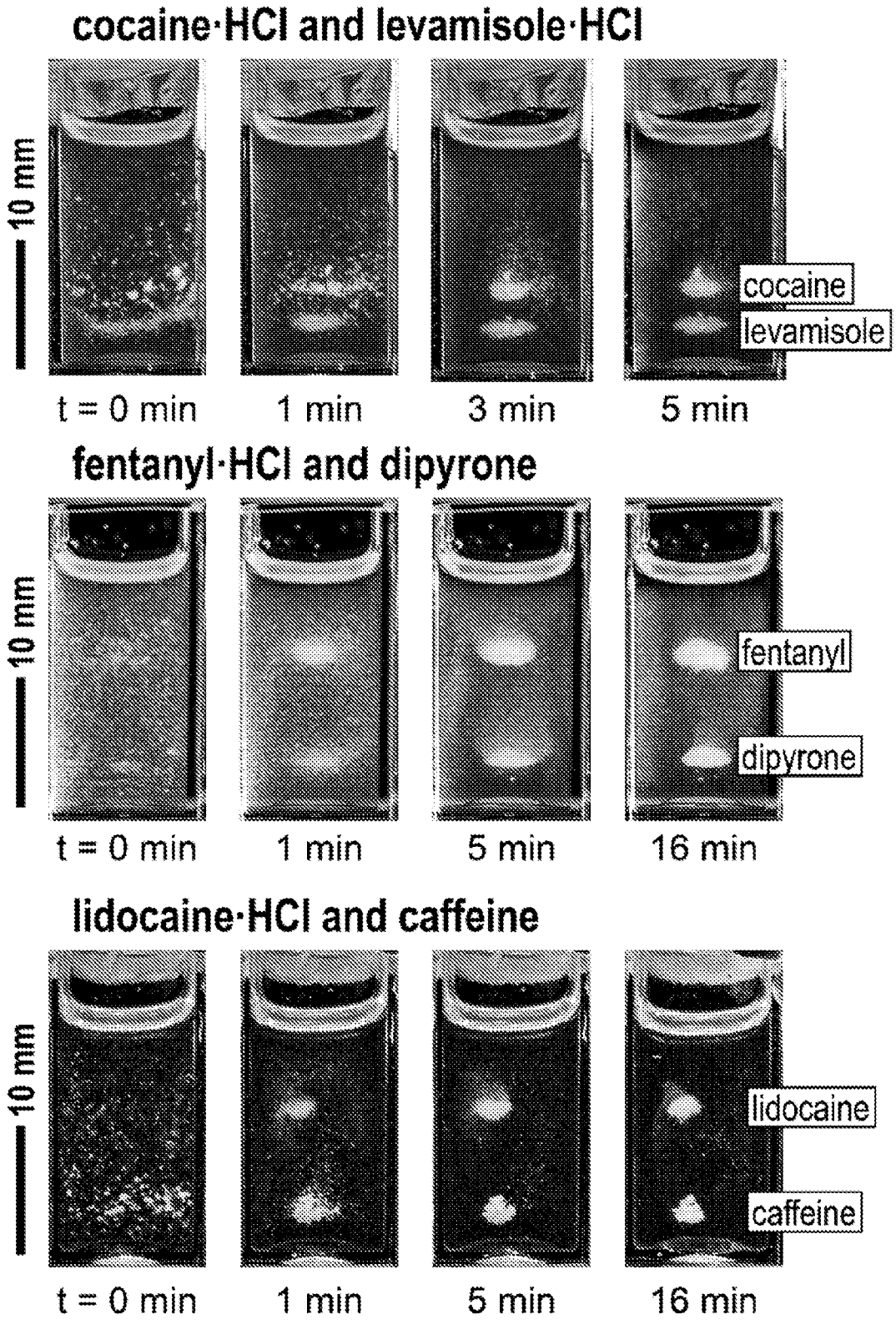

cocaine·HCl and levamisole·HCl
10 mm
cocaine
levamisole
t = 0 min
1 min
3 min
5 min
fentanyl·HCl and dipyrone
10 mm
fentanyl
dipyrone
t = 0 min
1 min
5 min
16 min
lidocaine·HCl and caffeine
10 mm
lidocaine
caffeine
t = 0 min
1 min
5 min
16 min

FIG. 11A

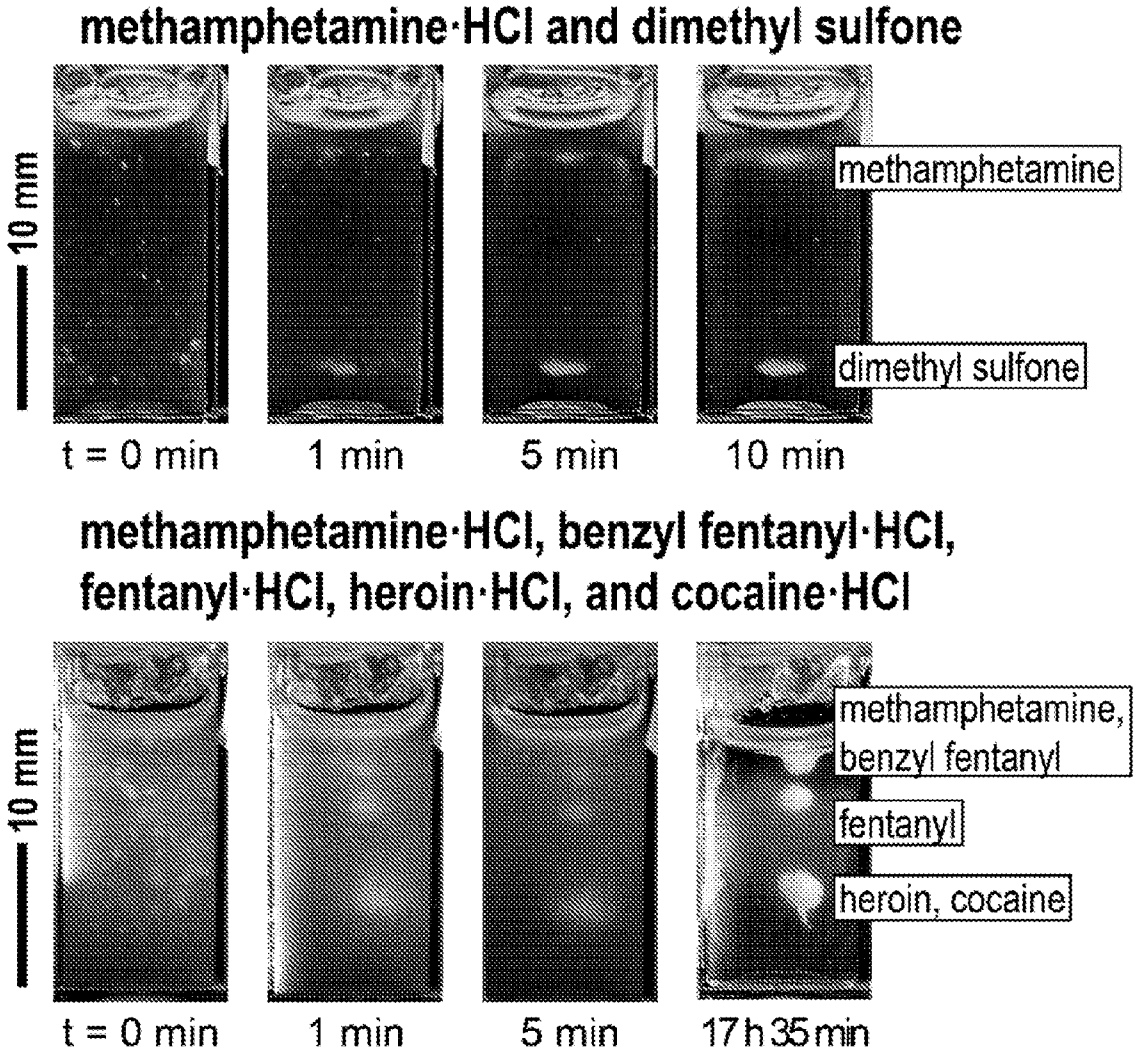
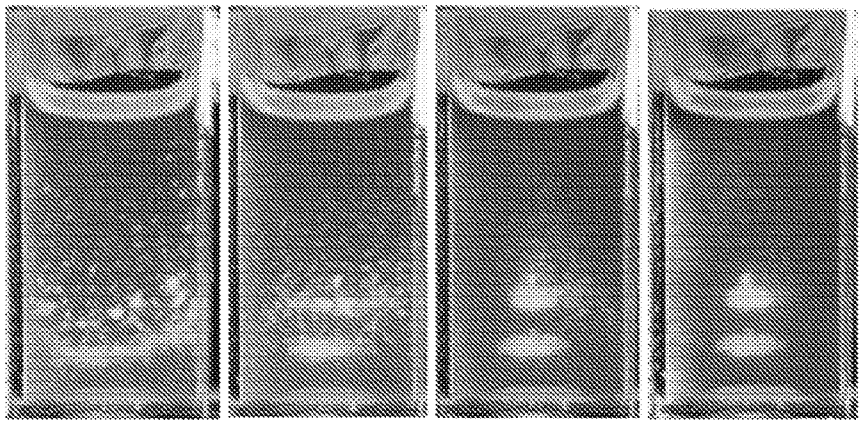
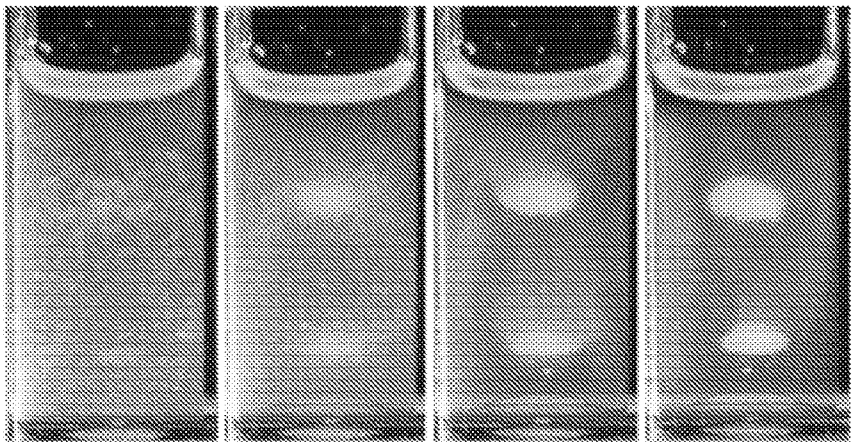

methamphetamine·HCl and dimethyl sulfone
10 mm
methamphetamine
dimethyl sulfone
t = 0 min
1 min
5 min
10 min
methamphetamine·HCl, benzyl fentanyl·HCl,
fentanyl·HCl, heroin·HCl, and cocaine·HCl
10 mm
methamphetamine,
benzyl fentanyl
fentanyl
heroin, cocaine
t = 0 min
1 min
5 min
17 h 35 min

FIG. 11A cont.

cocaine·HCl and levamisole·HCl



fentanyl·HCl and dipyrone



lidocaine·HCl and caffeine

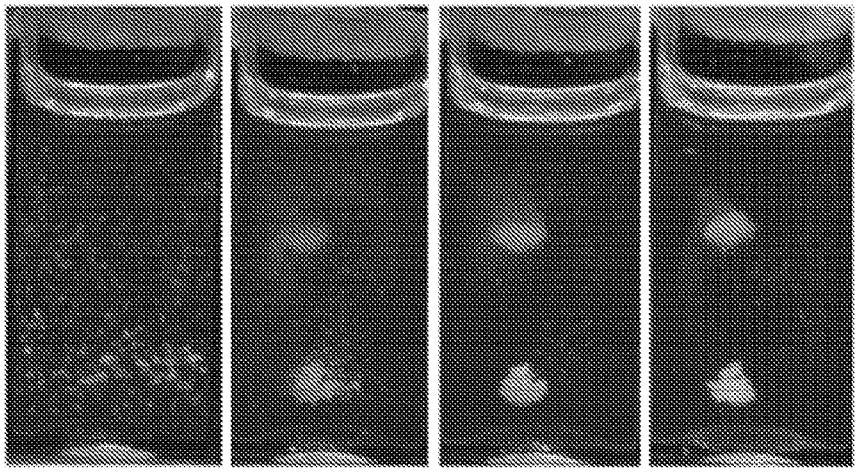


FIG. 11B

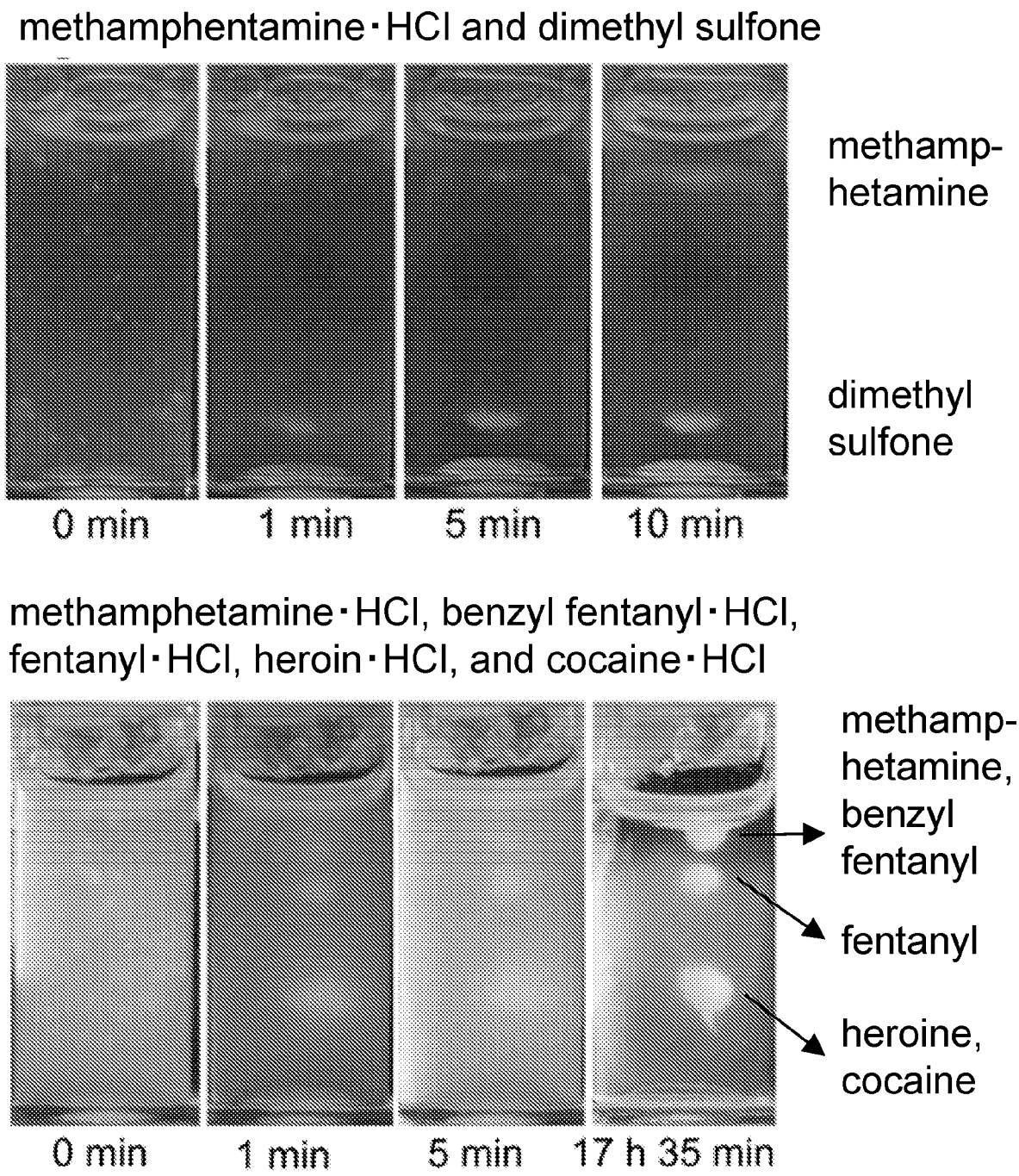

methamphentamine·HCl and dimethyl sulfone
methamp-
hetamine
dimethyl
sulfone
0 min
1 min
5 min
10 min
methamphetamine·HCl, benzyl fentanyl·HCl,
fentanyl·HCl, heroin·HCl, and cocaine·HCl
methamp-
hetamine,
benzyl
fentanyl
fentanyl
heroine,
cocaine
0 min
1 min
5 min
17 h 35 min

FIG. 11B cont.

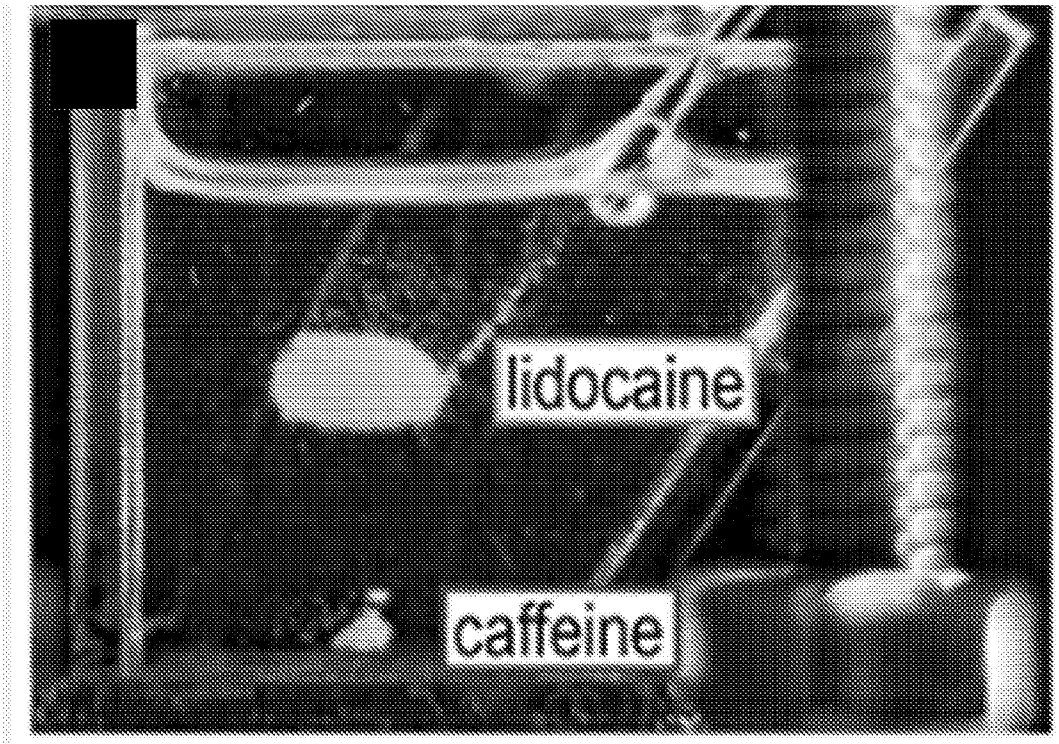


FIG. 12A

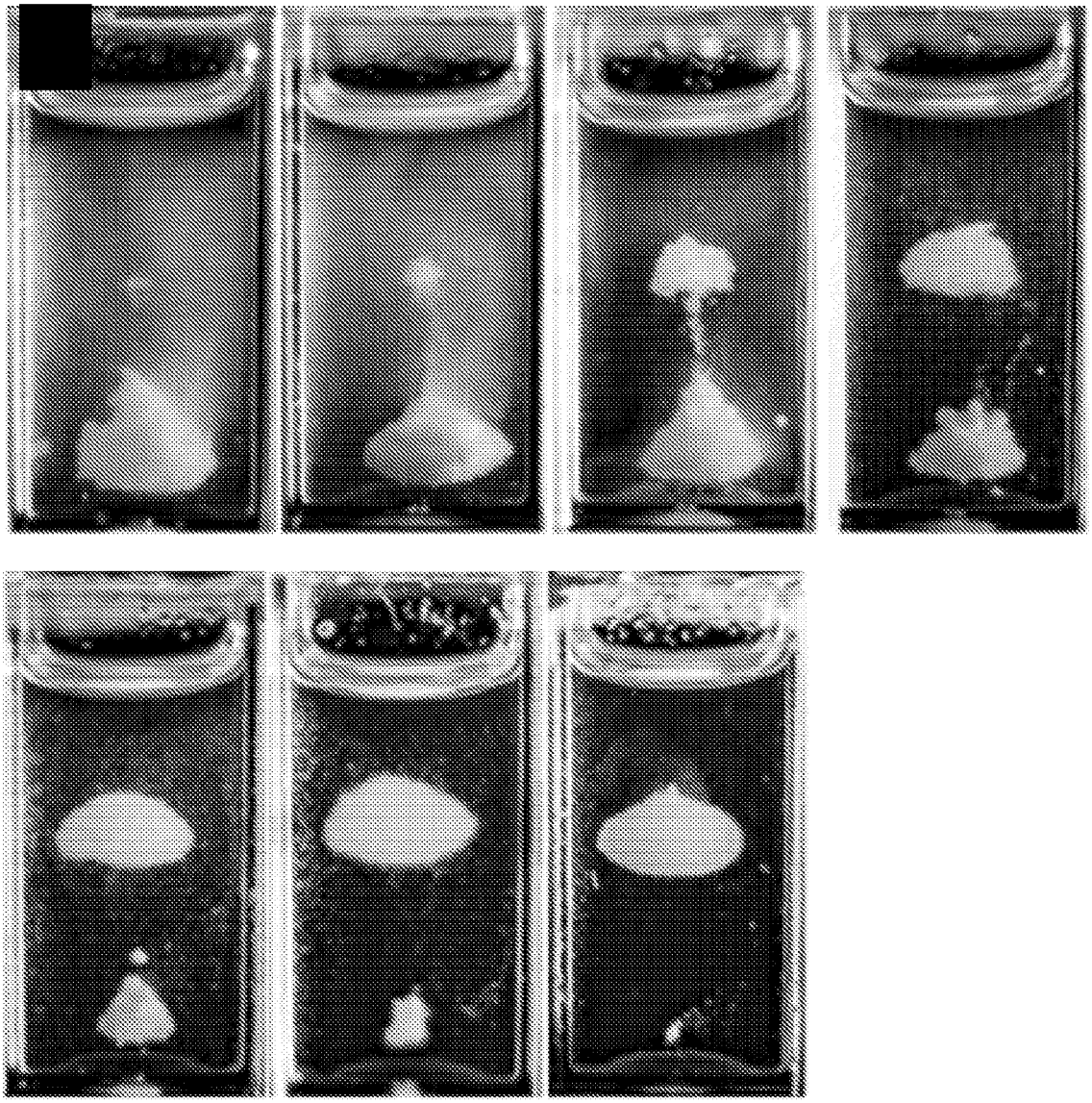
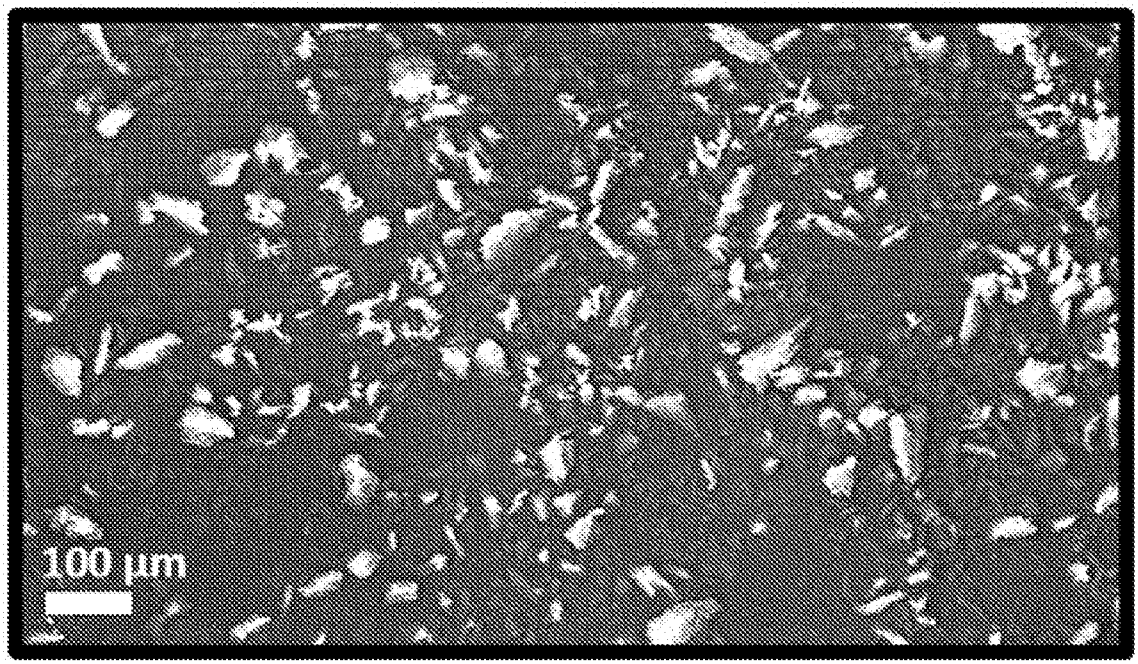


FIG. 12B

caffeine



lidocaine·HCl

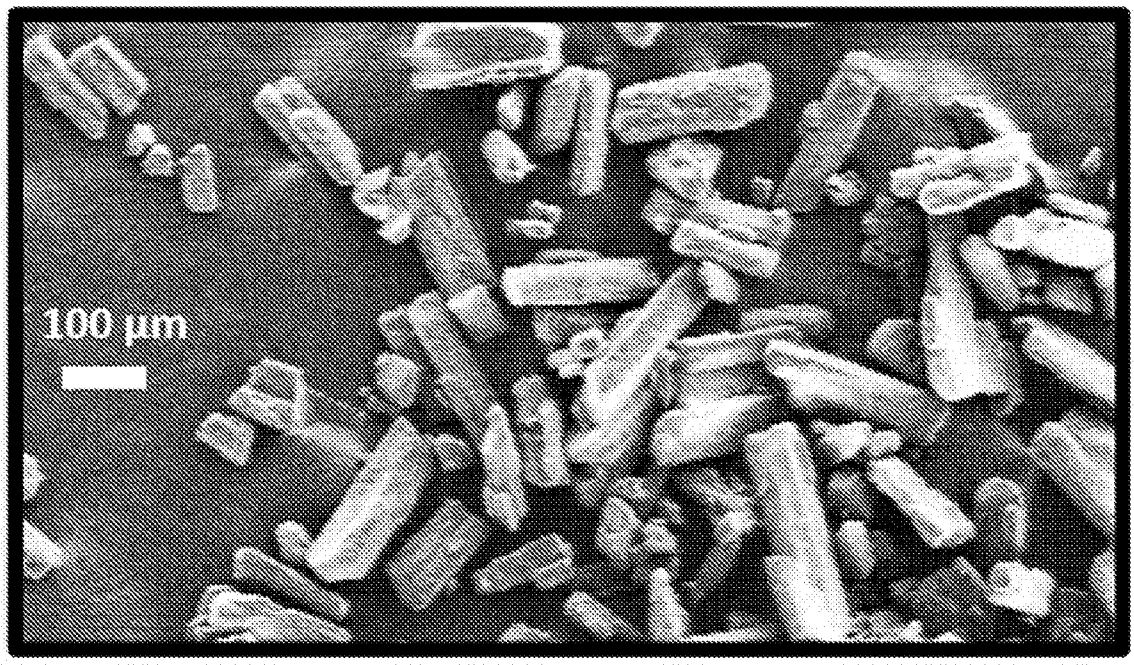


FIG. 12C

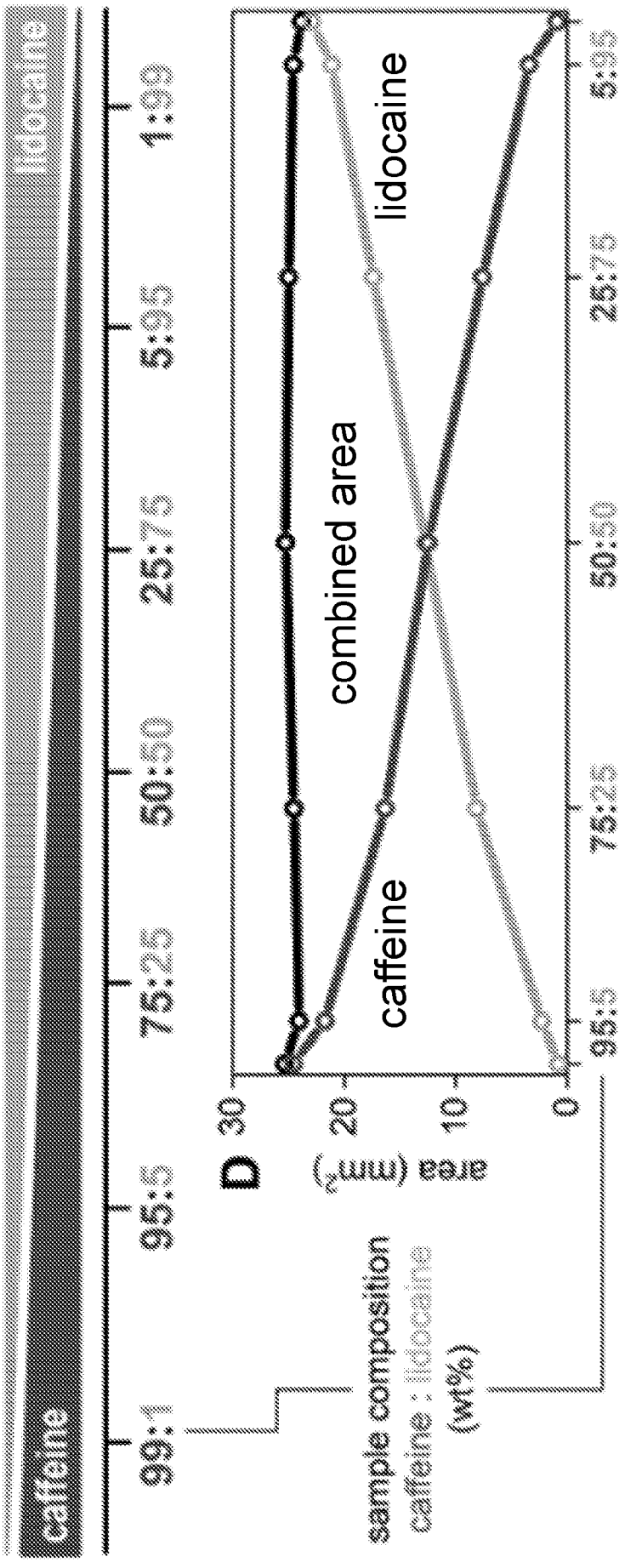

caffeine
lidocaine
99:1
95:5
75:25
50:50
25:75
5:95
1:99
sample composition
caffeine : lidocaine
(wt%)
D
area (mm²)
30
20
10
0
combined area
caffeine
lidocaine

FIG. 12D

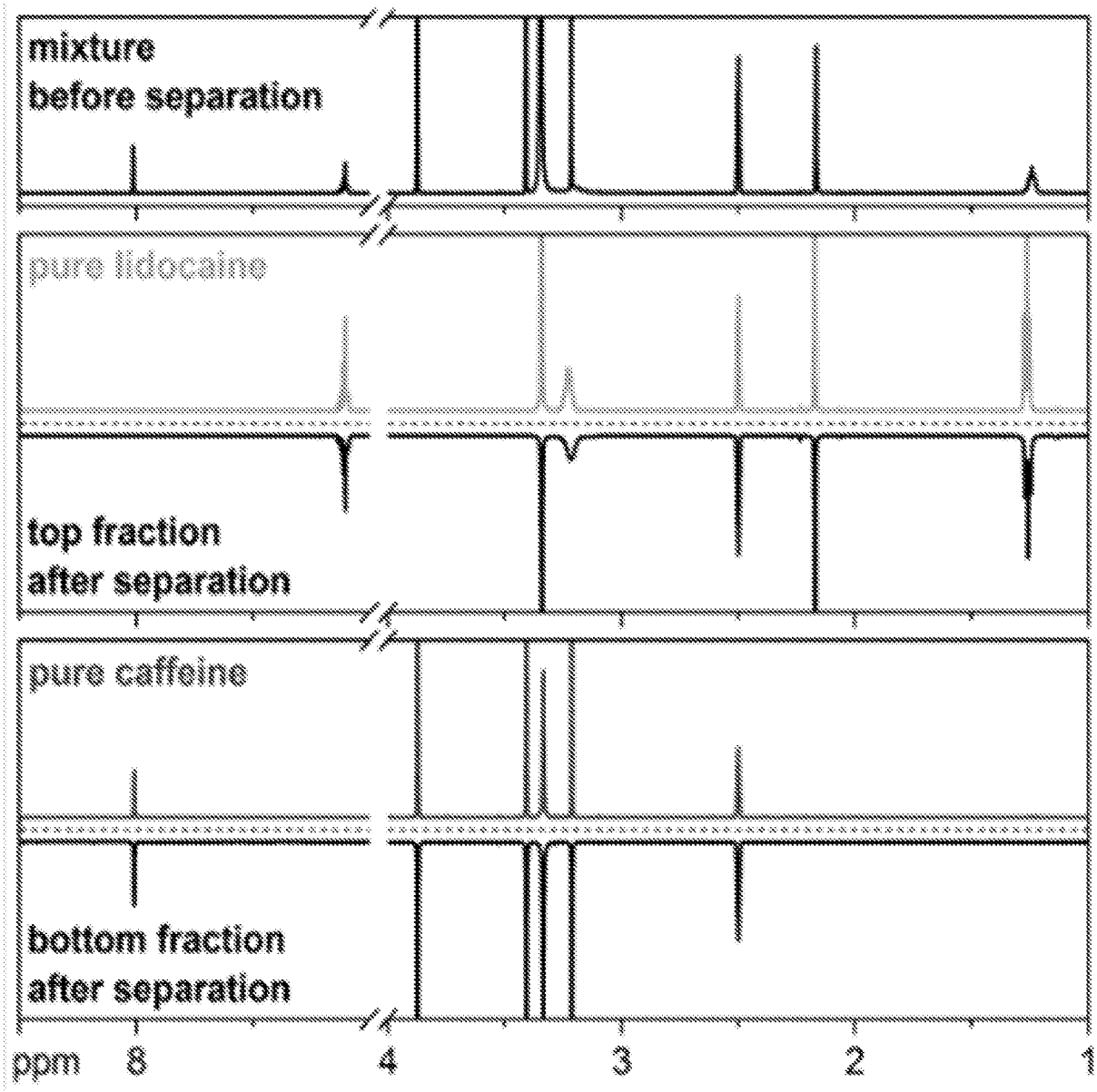

mixture
before separation
pure lidocaine
top fraction
after separation
pure caffeine
bottom fraction
after separation
ppm
8
4
3
2
1

FIG. 12E

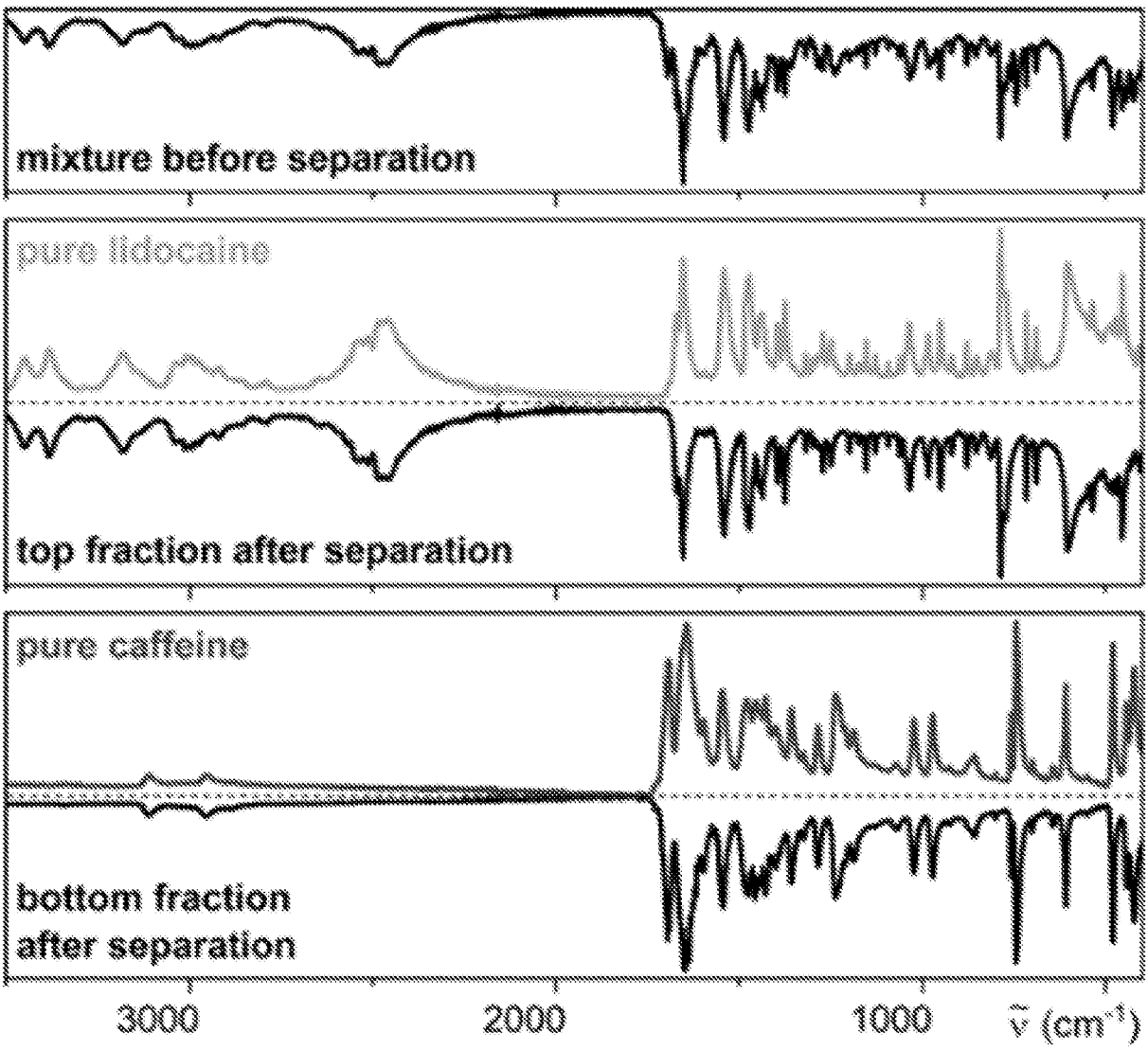

mixture before separation
pure lidocaine
top fraction after separation
pure caffeine
bottom fraction
after separation
3000
2000
1000
$\tilde{\nu}$ (cm^{-1})

FIG. 12F

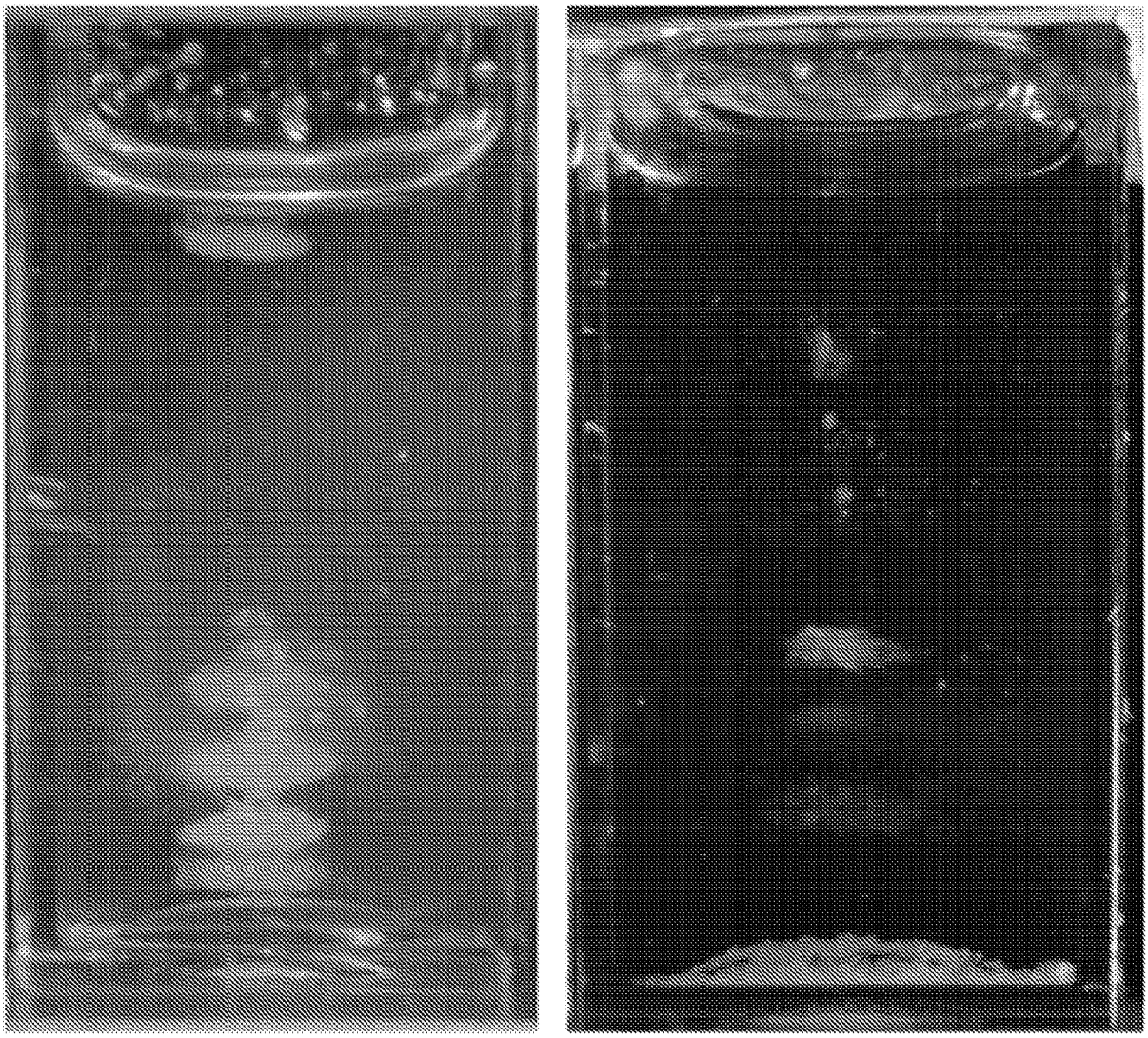


FIG. 12G

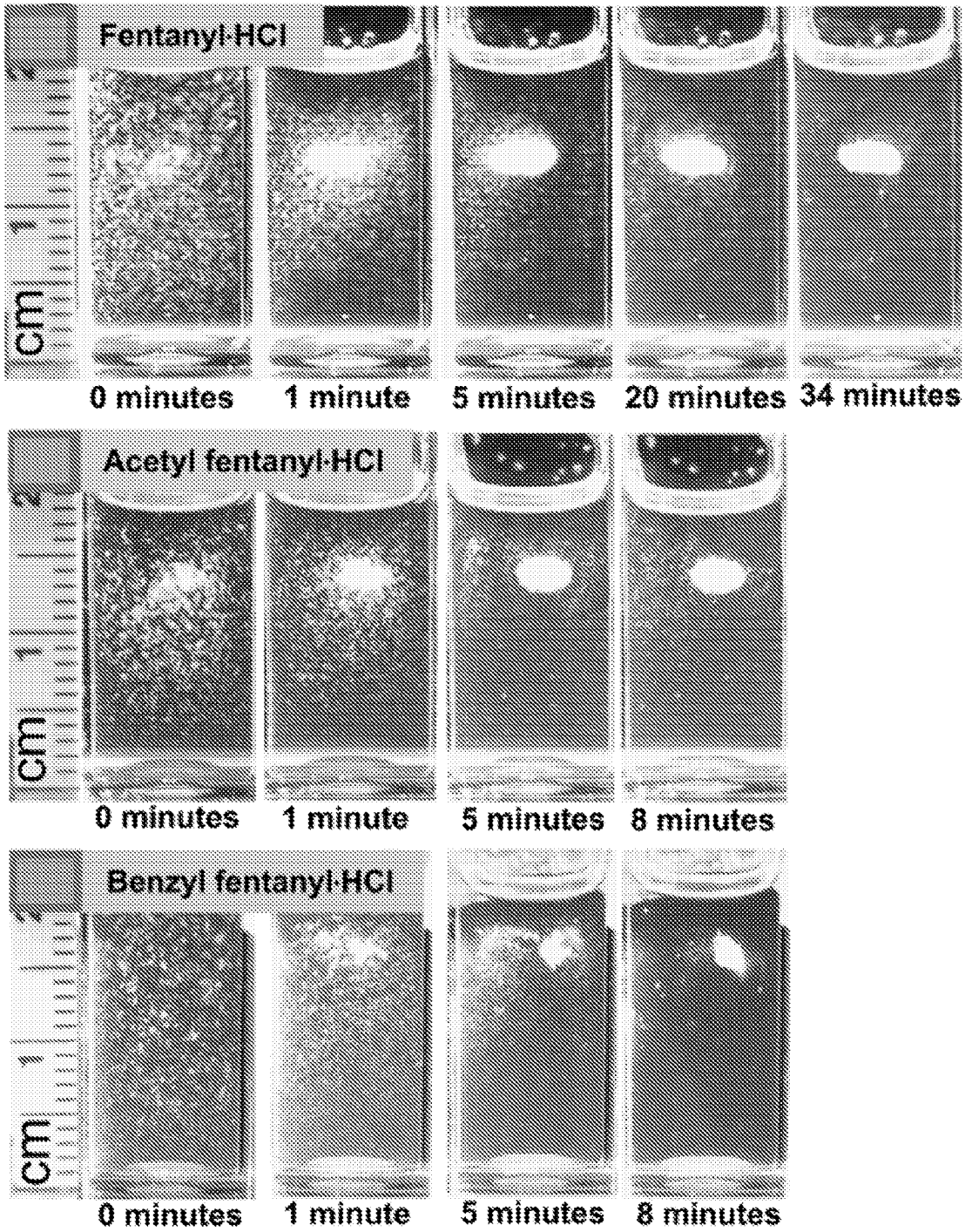

Fentanyl·HCl
cm
0 minutes
1 minute
5 minutes
20 minutes
34 minutes
Acetyl fentanyl·HCl
cm
0 minutes
1 minute
5 minutes
8 minutes
Benzyl fentanyl·HCl
cm
0 minutes
1 minute
5 minutes
8 minutes

FIG. 13

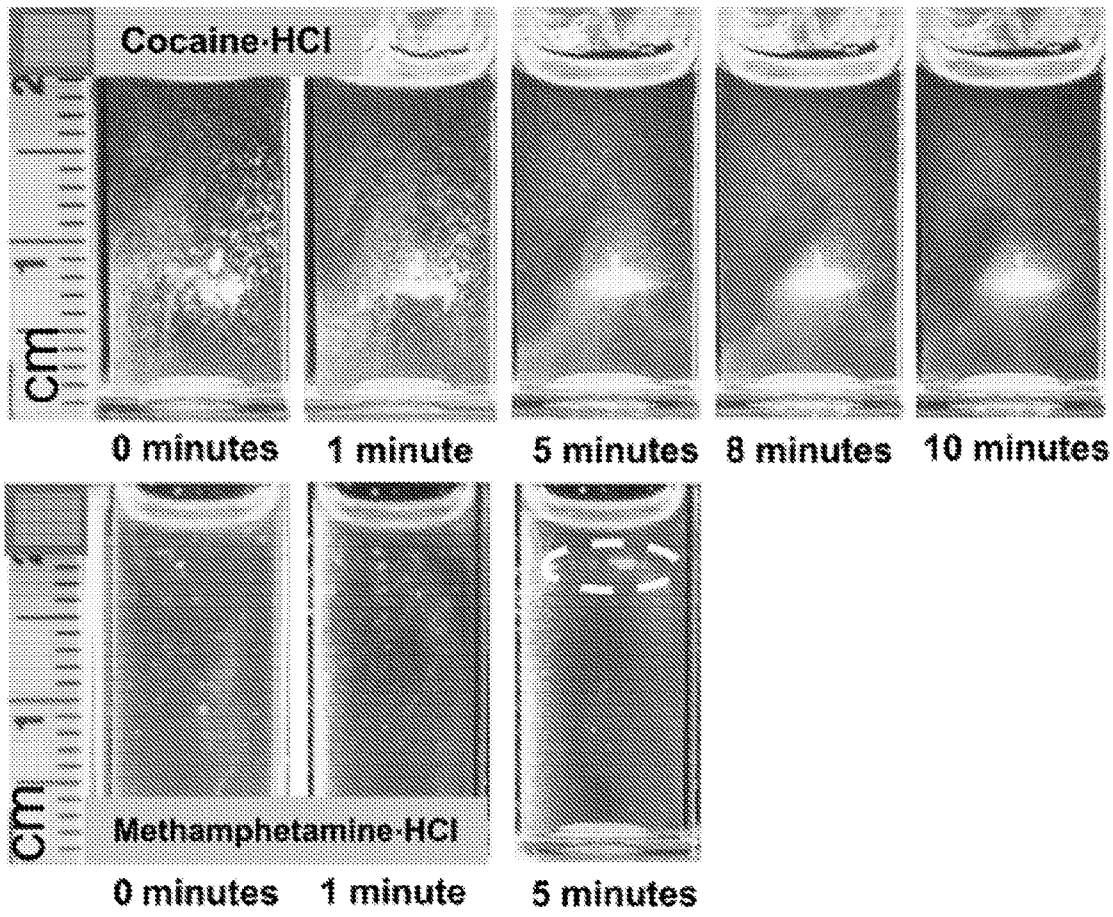

Cocaine·HCl
cm
0 minutes
1 minute
5 minutes
8 minutes
10 minutes
cm
Methamphetamine·HCl
0 minutes
1 minute
5 minutes

FIG. 13 cont.

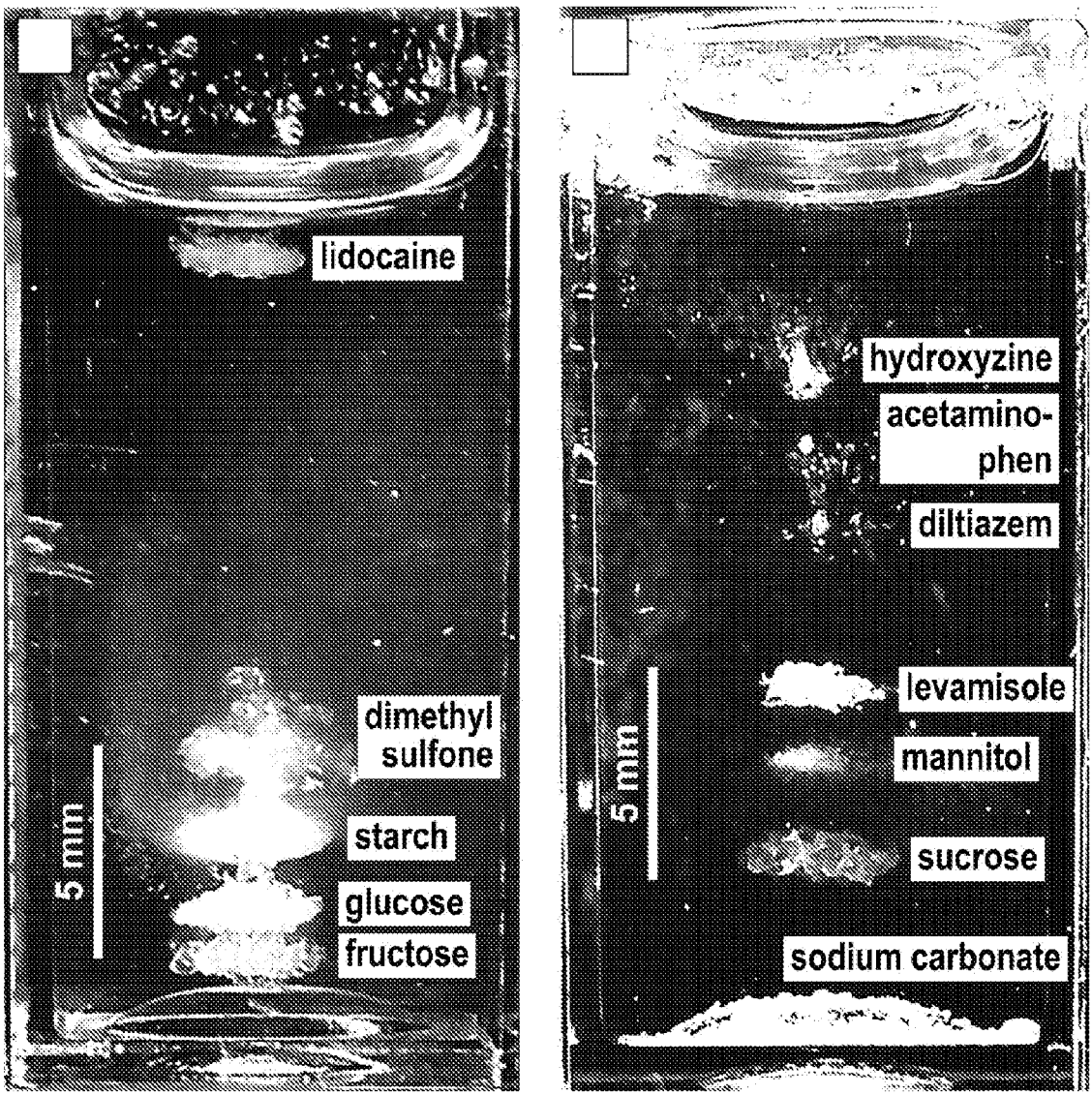

lidocaine
dimethyl sulfone
starch
glucose
fructose
5 mm
hydroxyzine
acetamino-phen
diltiazem
levamisole
mannitol
sucrose
sodium carbonate
5 mm

FIG. 14

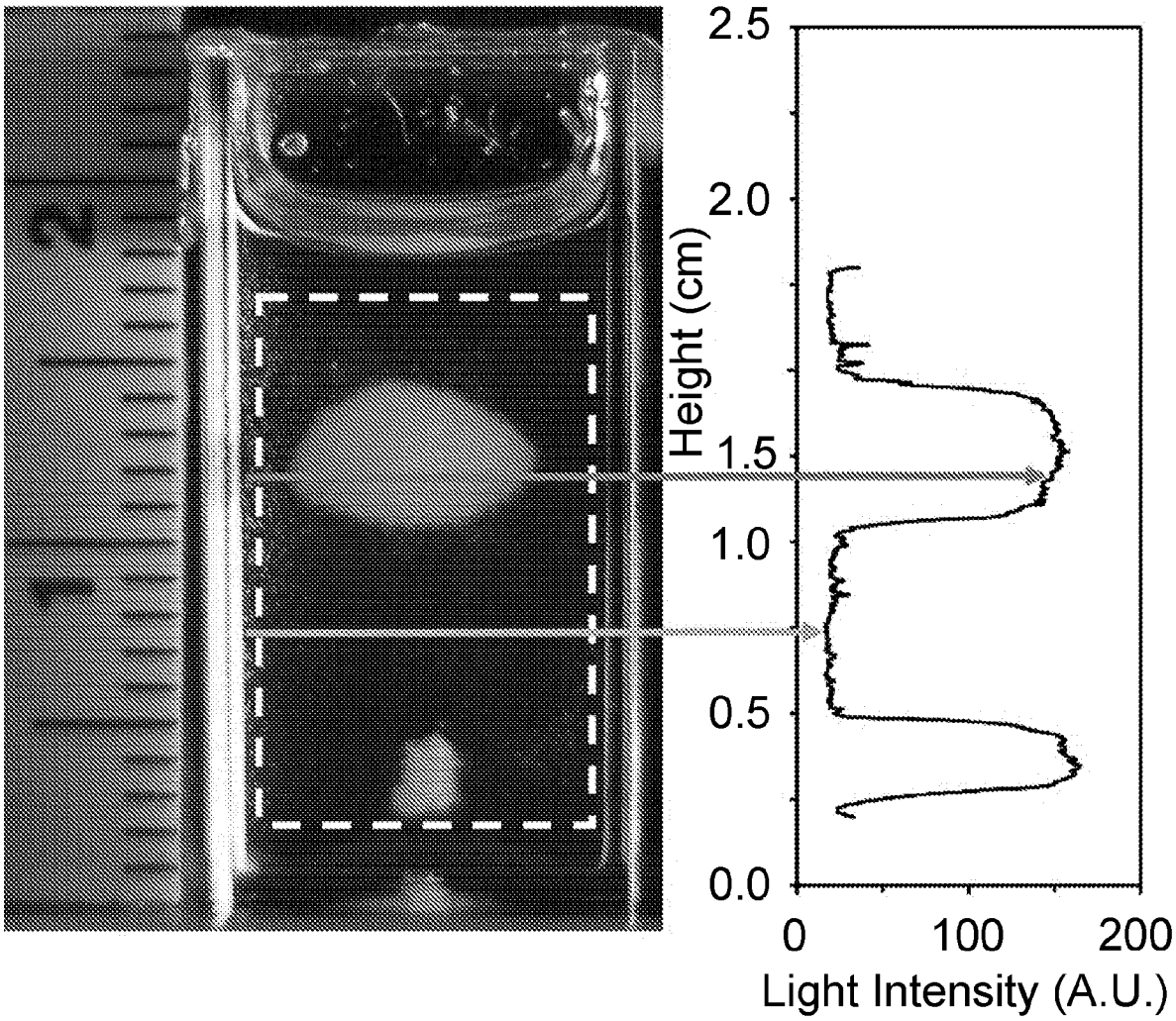


FIG. 15

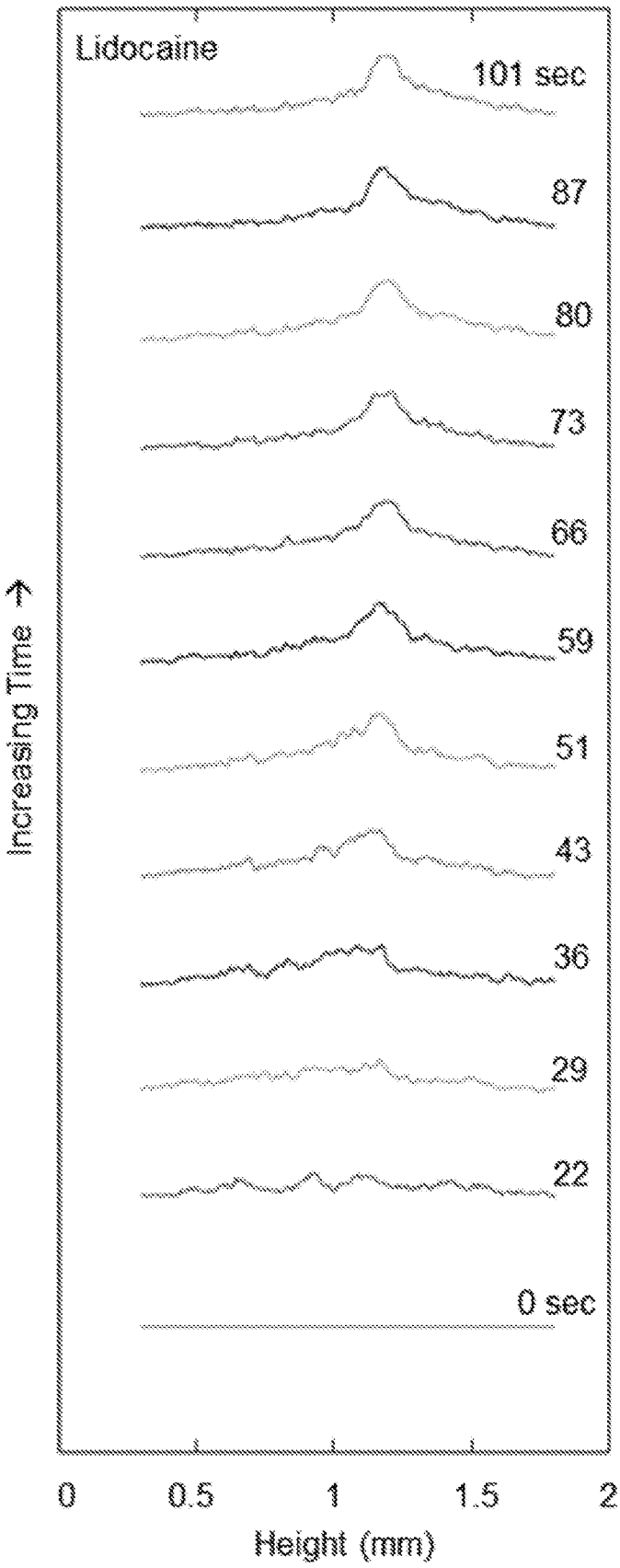

Lidocaine
101 sec
87
80
73
66
59
51
43
36
29
22
0 sec
Increasing Time
0
0.5
1
1.5
2
Height (mm)

FIG. 16

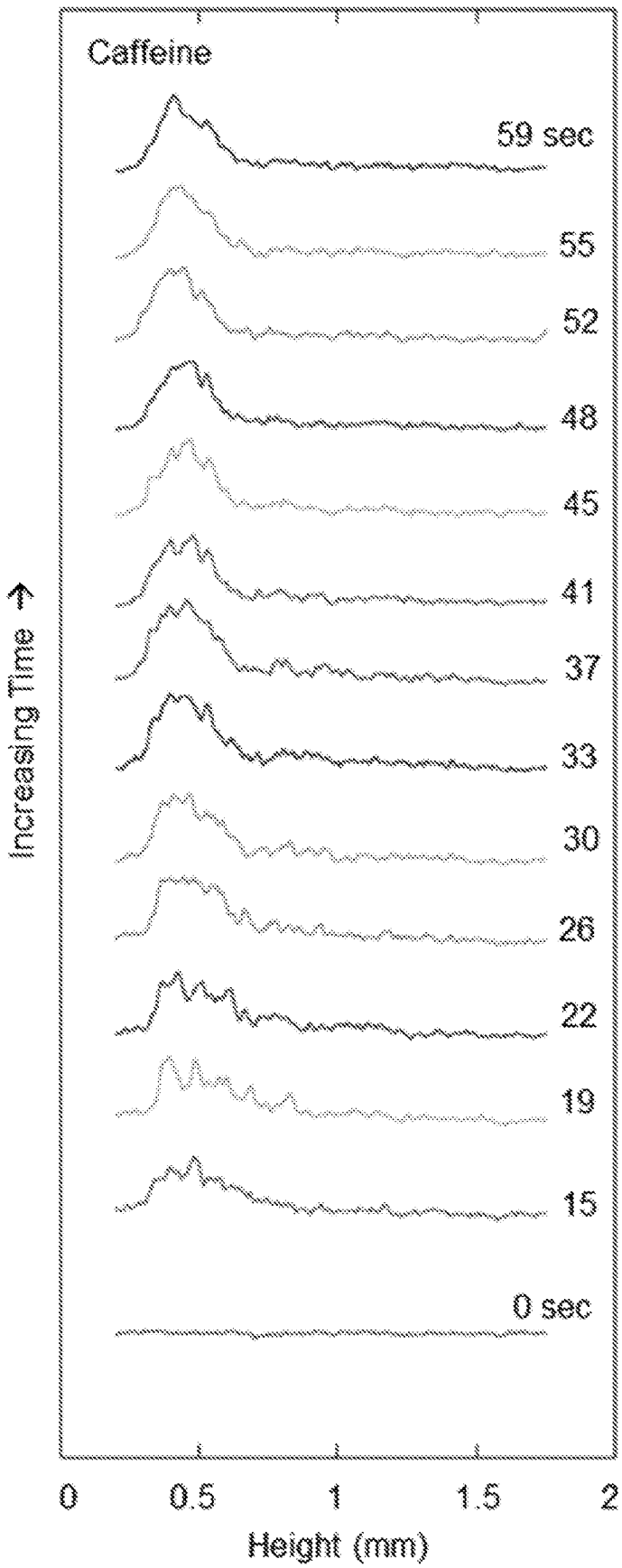

Caffeine
59 sec
55
52
48
45
41
37
33
30
26
22
19
15
0 sec
Increasing Time
0
0.5
1
1.5
2
Height (mm)

FIG. 16 cont.

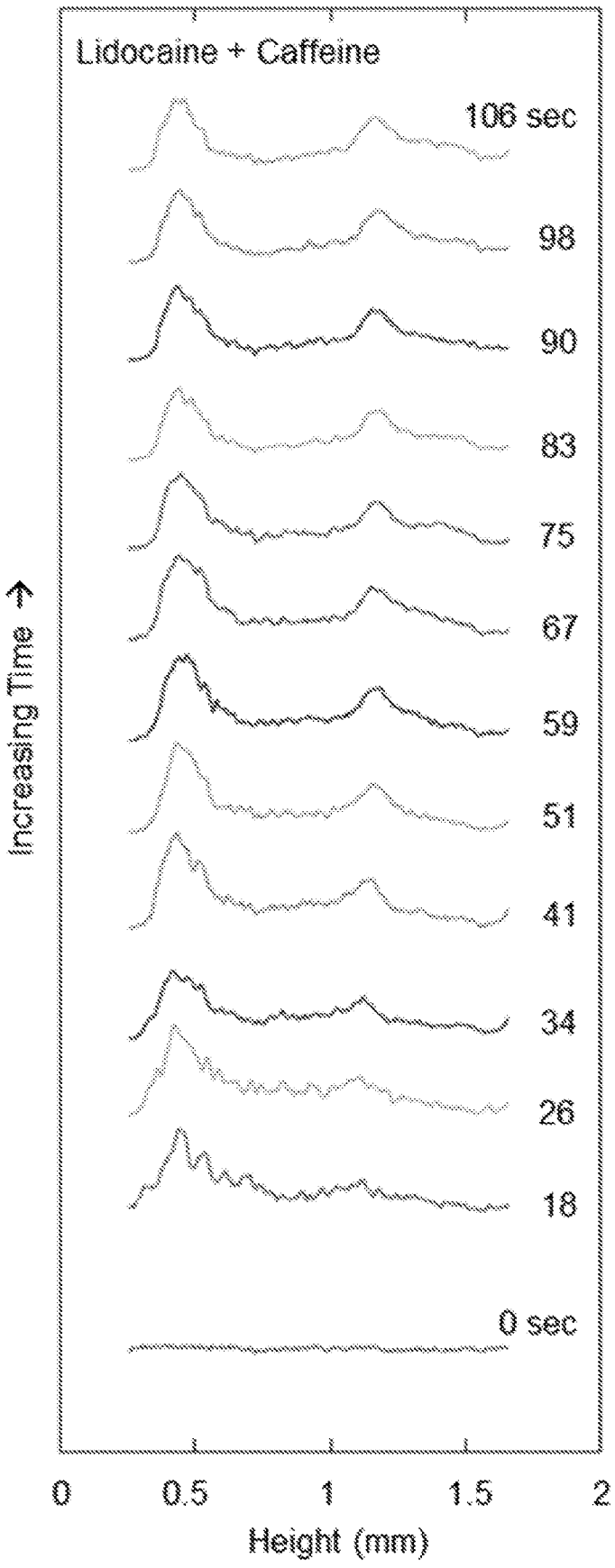

Lidocaine + Caffeine
106 sec
98
90
83
75
67
59
51
41
34
26
18
0 sec
Increasing Time
0
0.5
1
1.5
2
Height (mm)

FIG. 16 cont.

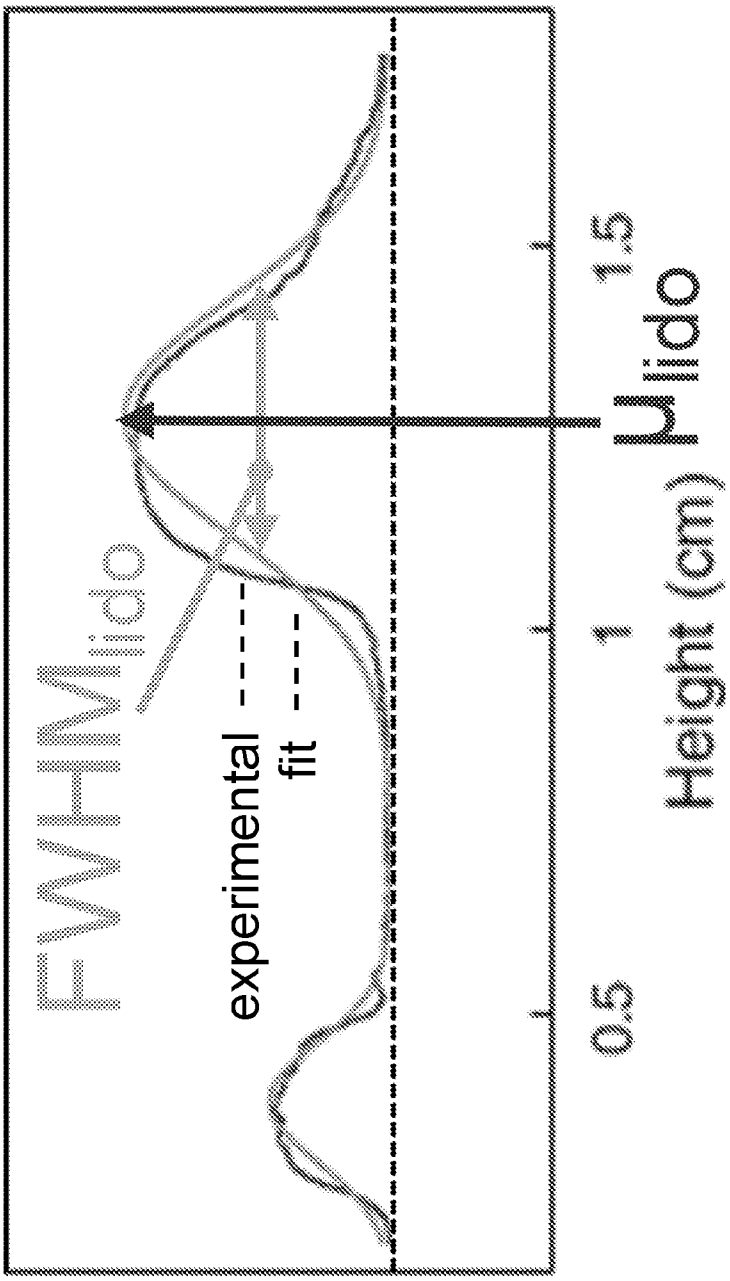
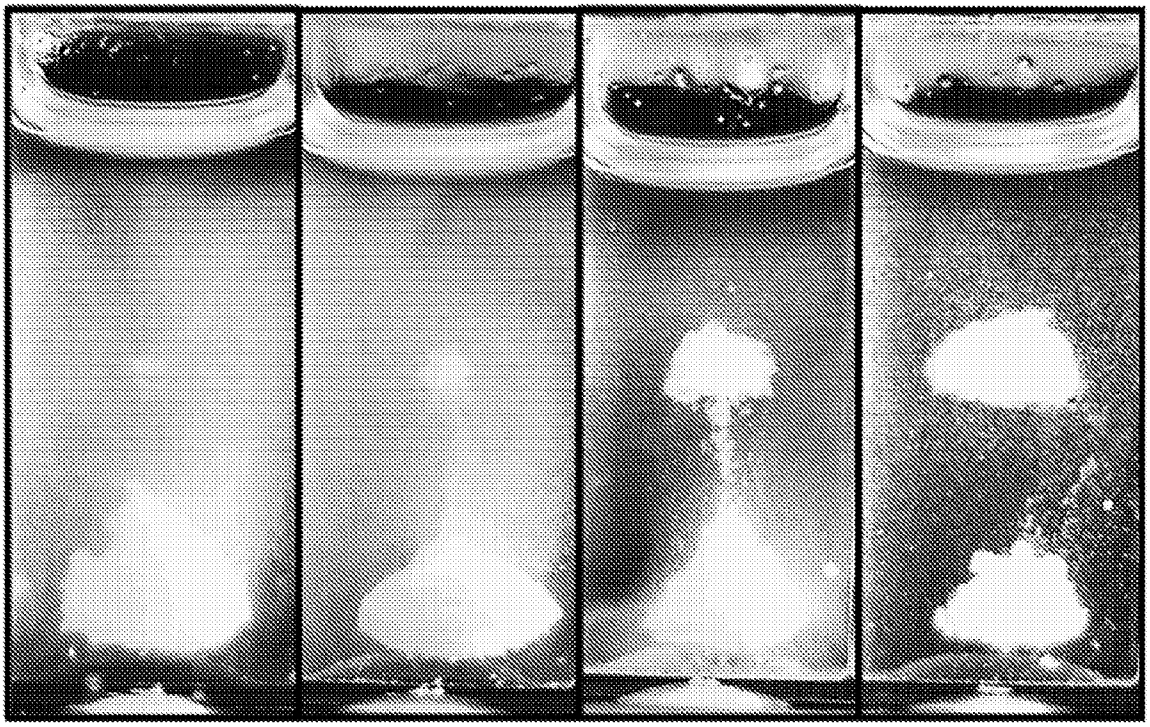


FIG. 17


1% Lidocaine
99% Caffeine
5% Lidocaine
95% Caffeine
25% Lidocaine
75% Caffeine
50% Lidocaine
50% Caffeine

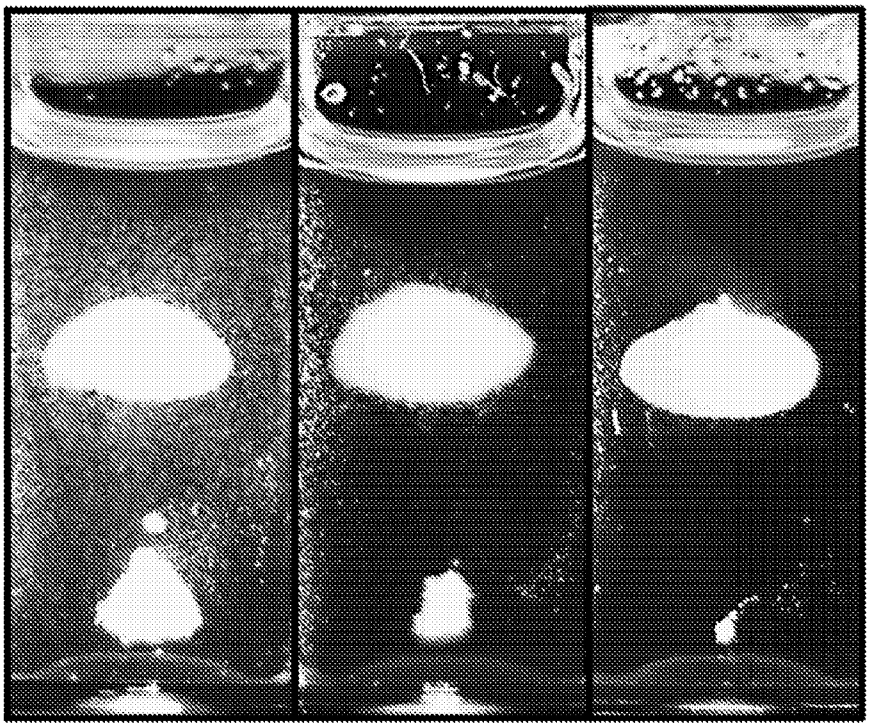

75% Lidocaine
25% Caffeine
95% Lidocaine
5% Caffeine
99% Lidocaine
1% Caffeine

FIG. 18

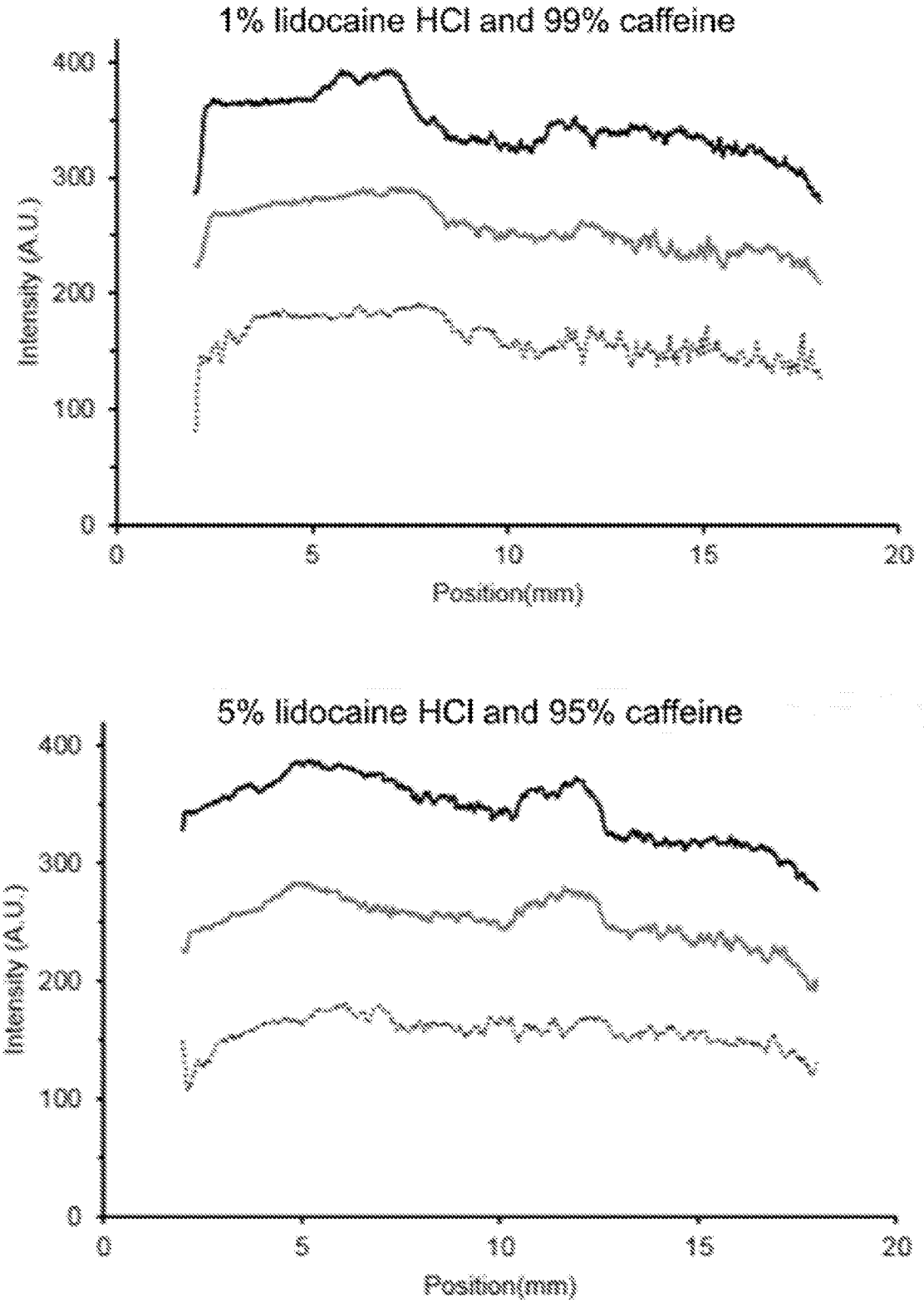
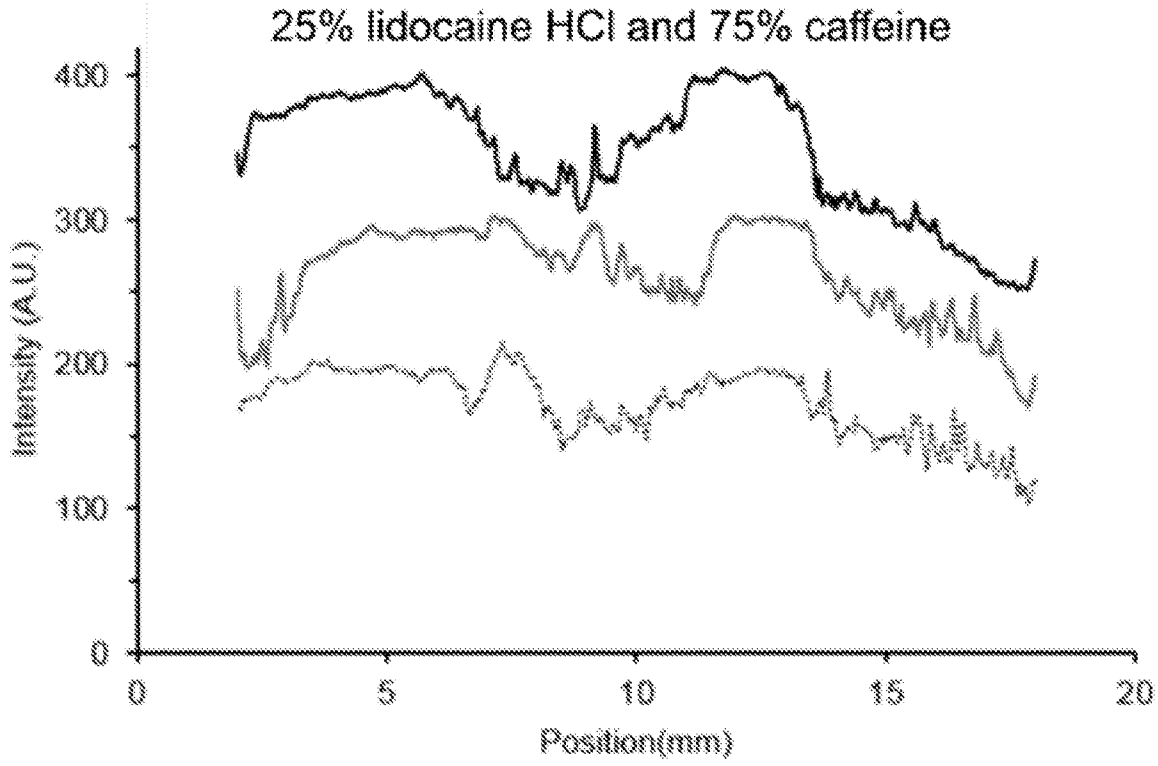

1% lidocaine HCl and 99% caffeine
Intensity (A.U.)
400
300
200
100
0
0
5
10
15
20
Position(mm)
5% lidocaine HCl and 95% caffeine
Intensity (A.U.)
400
300
200
100
0
0
5
10
15
20
Position(mm)

FIG. 19A


25% lidocaine HCl and 75% caffeine
Intensity (A.U.)
400
300
200
100
0
0
5
10
15
20
Position(mm)

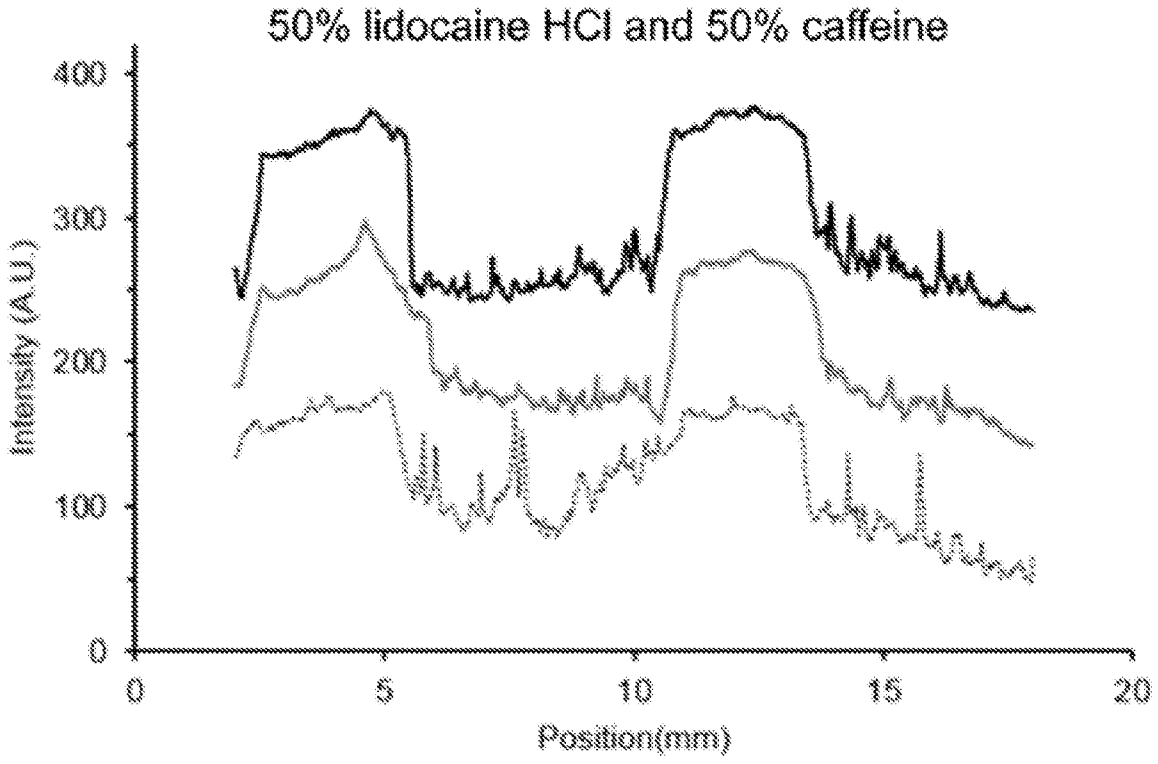

50% lidocaine HCl and 50% caffeine
Intensity (A.U.)
400
300
200
100
0
0
5
10
15
20
Position(mm)

FIG. 19A cont.

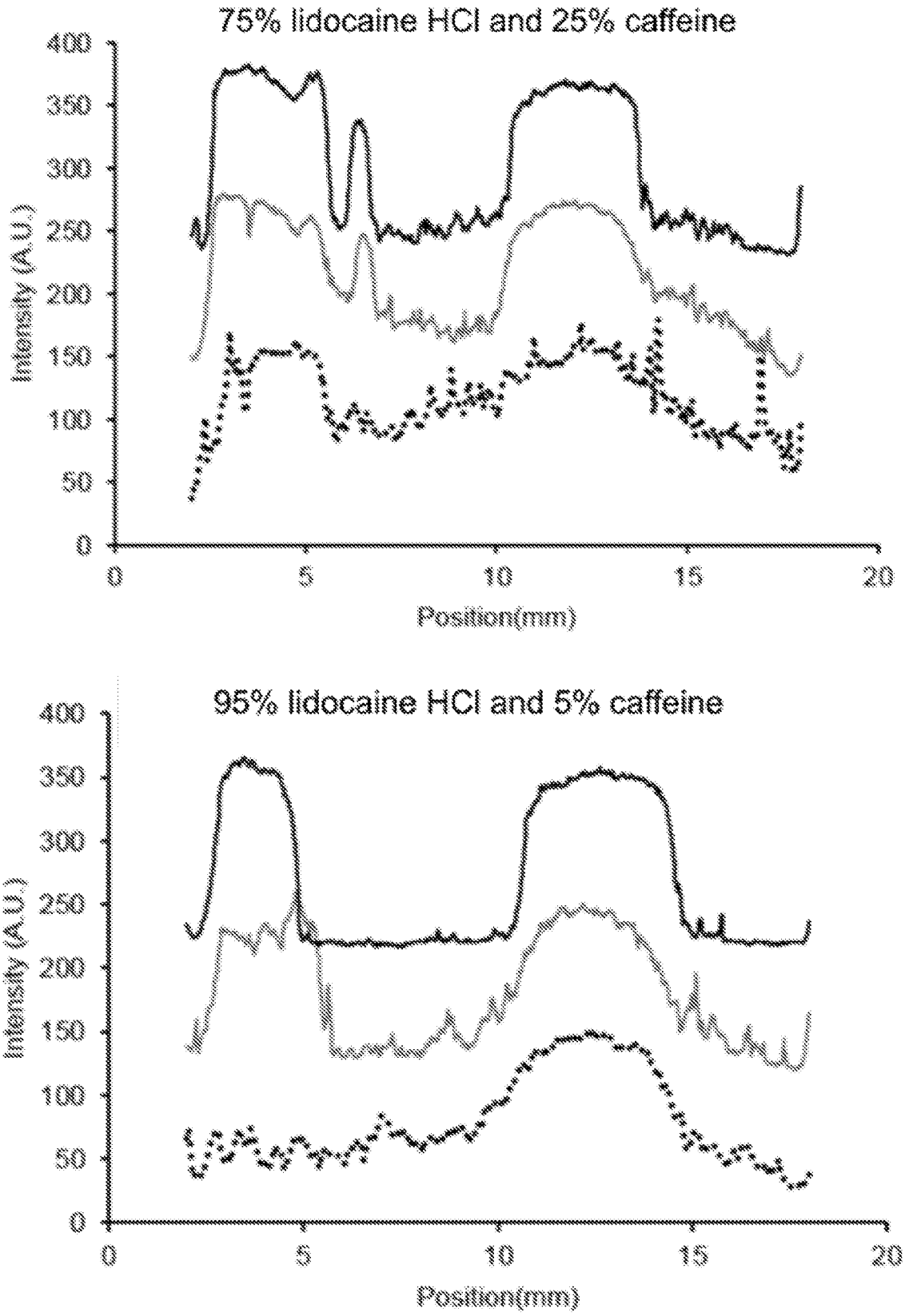
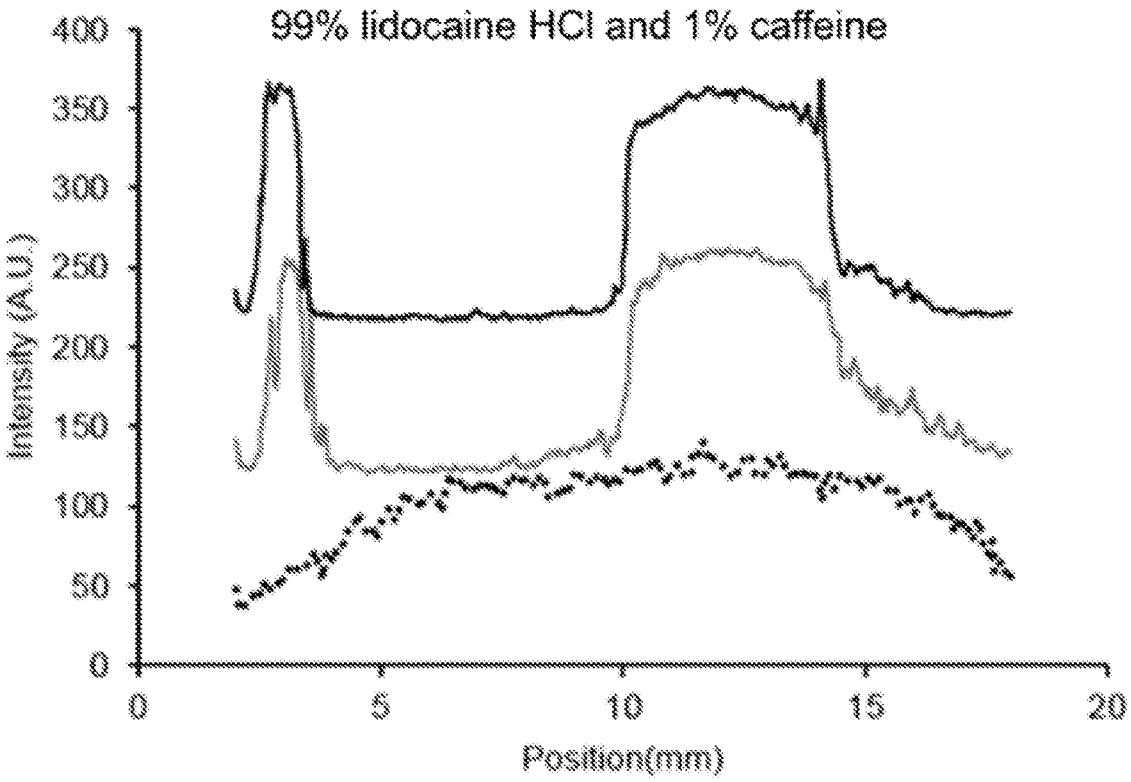
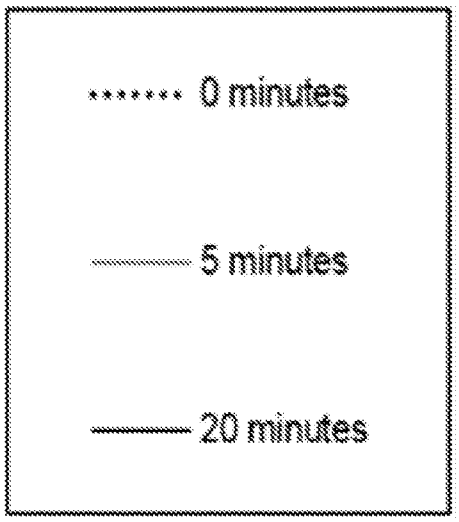

75% lidocaine HCl and 25% caffeine
Intensity (A.U.)
400
350
300
250
200
150
100
50
0
0
5
10
15
20
Position(mm)
95% lidocaine HCl and 5% caffeine
Intensity (A.U.)
400
350
300
250
200
150
100
50
0
0
5
10
15
20
Position(mm)

FIG. 19A cont.





Applies to all of FIG. 19A

FIG. 19A cont.

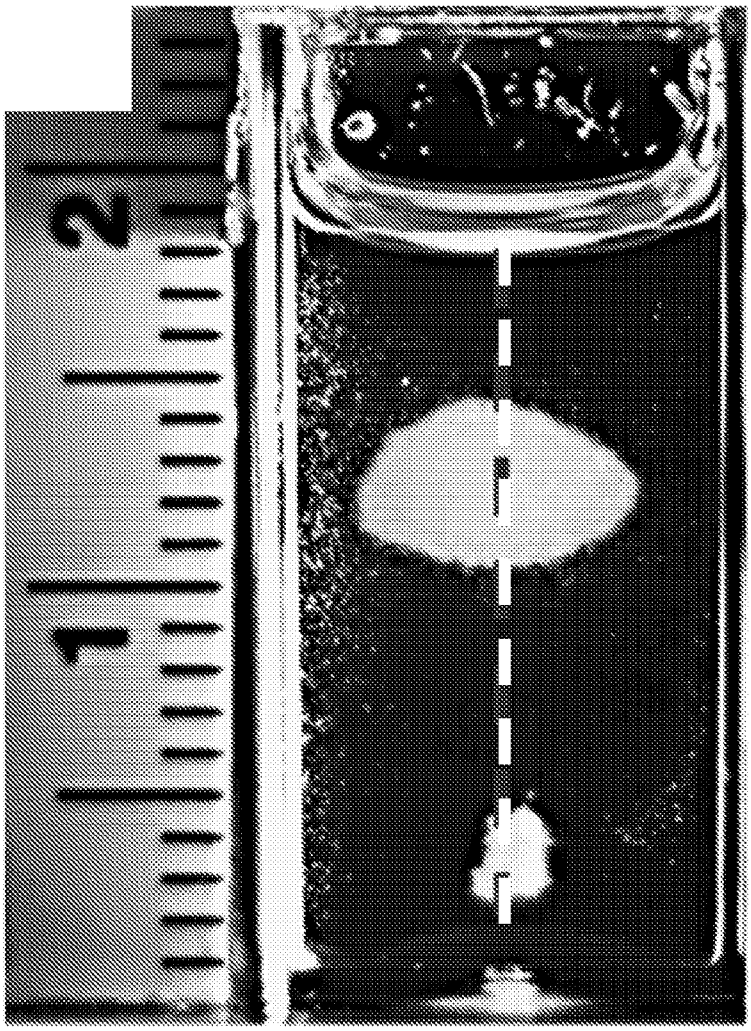


FIG. 19B

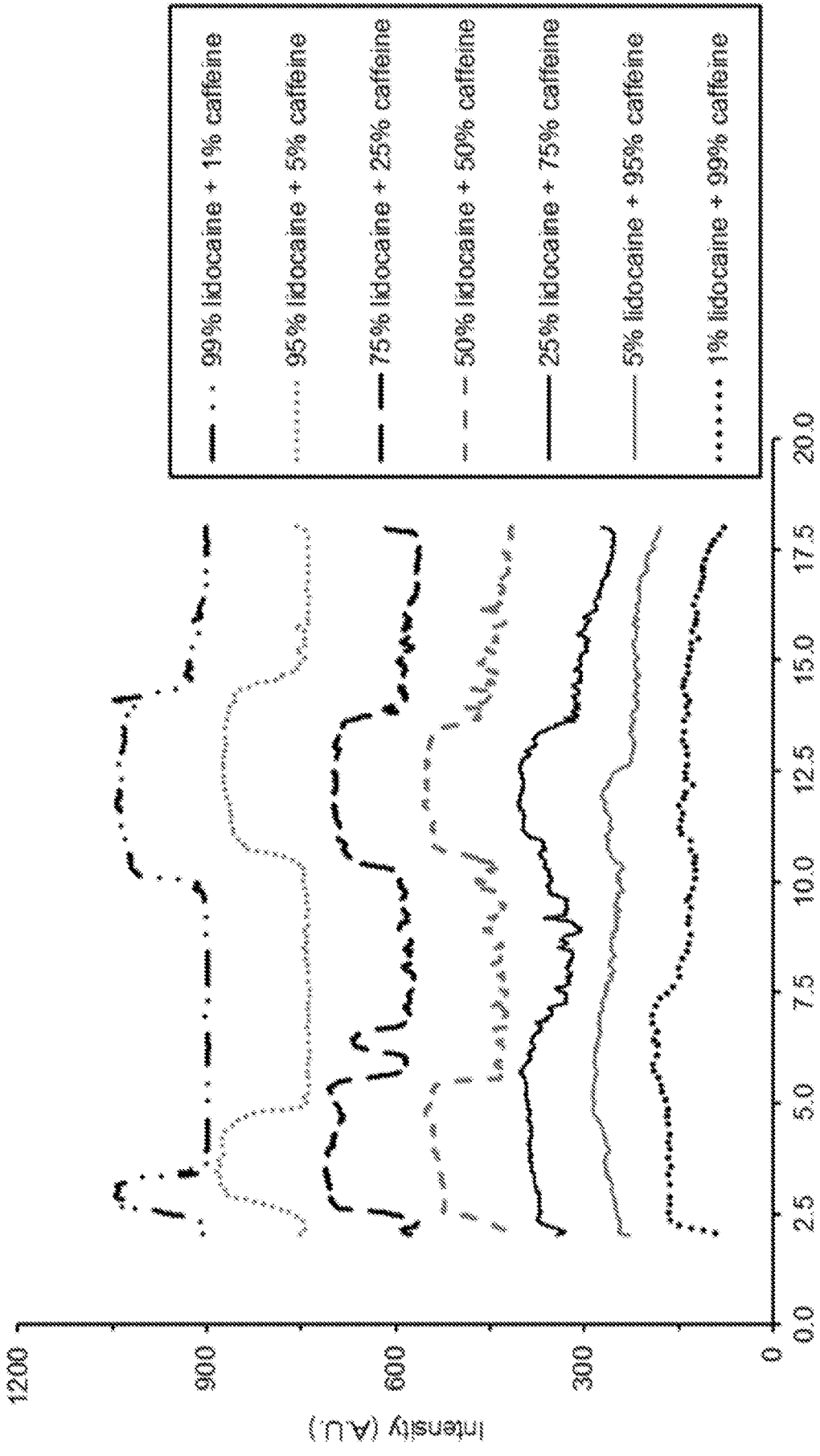

99% lidocaine + 1% caffeine
95% lidocaine + 5% caffeine
75% lidocaine + 25% caffeine
50% lidocaine + 50% caffeine
25% lidocaine + 75% caffeine
5% lidocaine + 95% caffeine
1% lidocaine + 99% caffeine
Intensity (A.U.)
1200
900
600
300
0
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
Position(mm)

FIG. 20

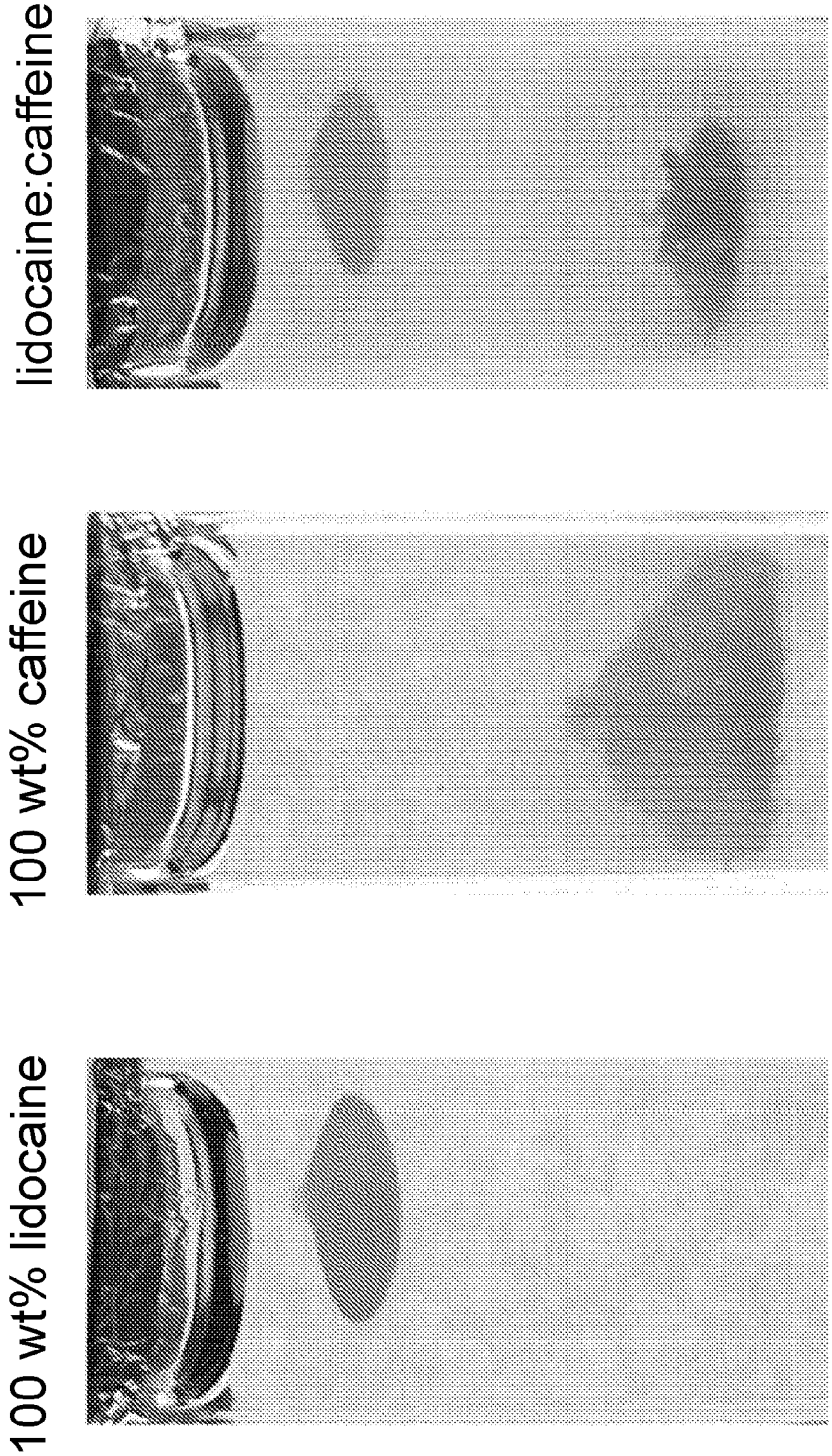

100 wt% lidocaine
100 wt% caffeine
50:50 wt%
lidocaine:caffeine

FIG. 21

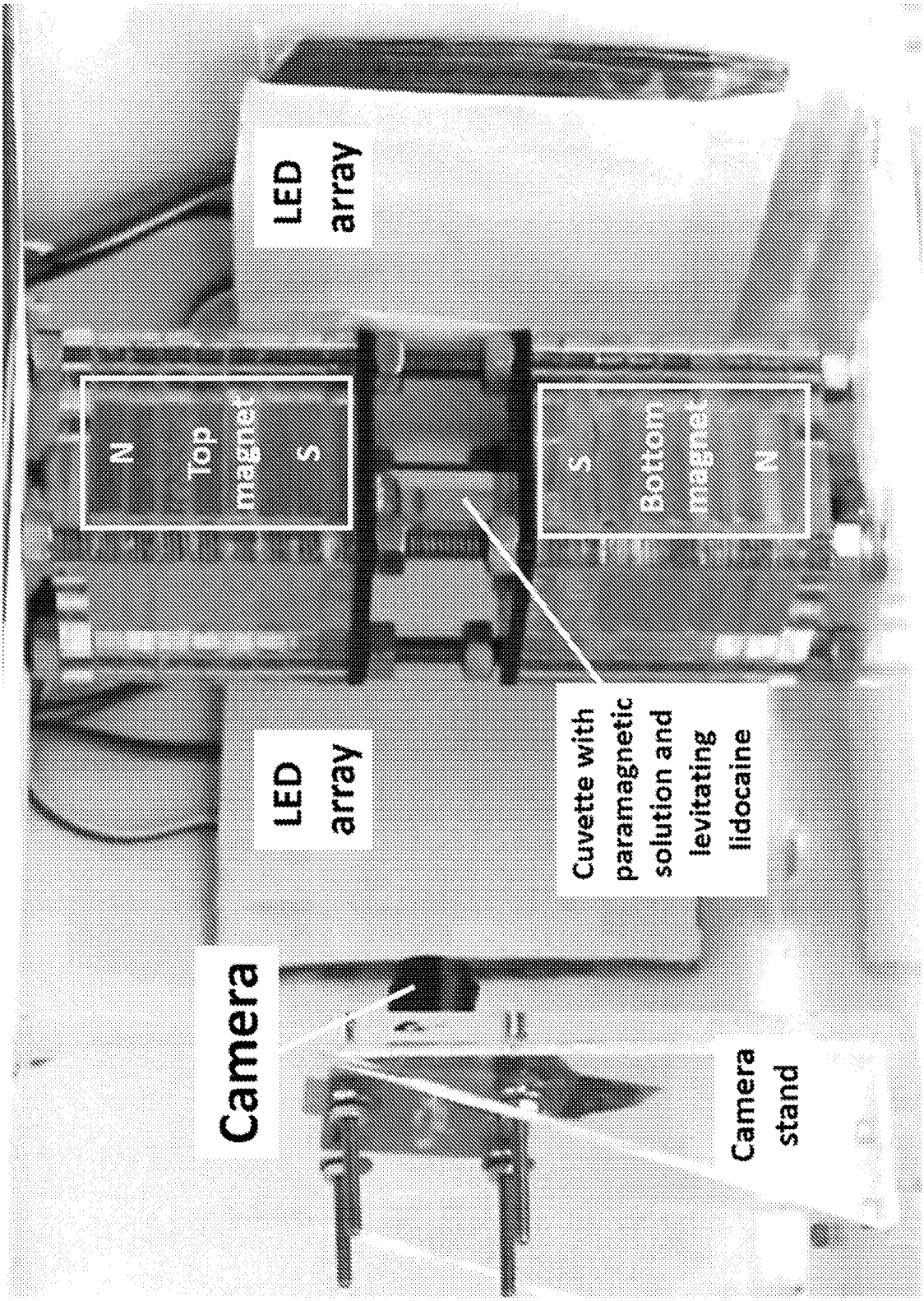

Camera
LED array
LED array
N
Top magnet
S
S
Bottom magnet
N
Cuvette with paramagnetic solution and levitating lidocaine
Camera stand

FIG. 22

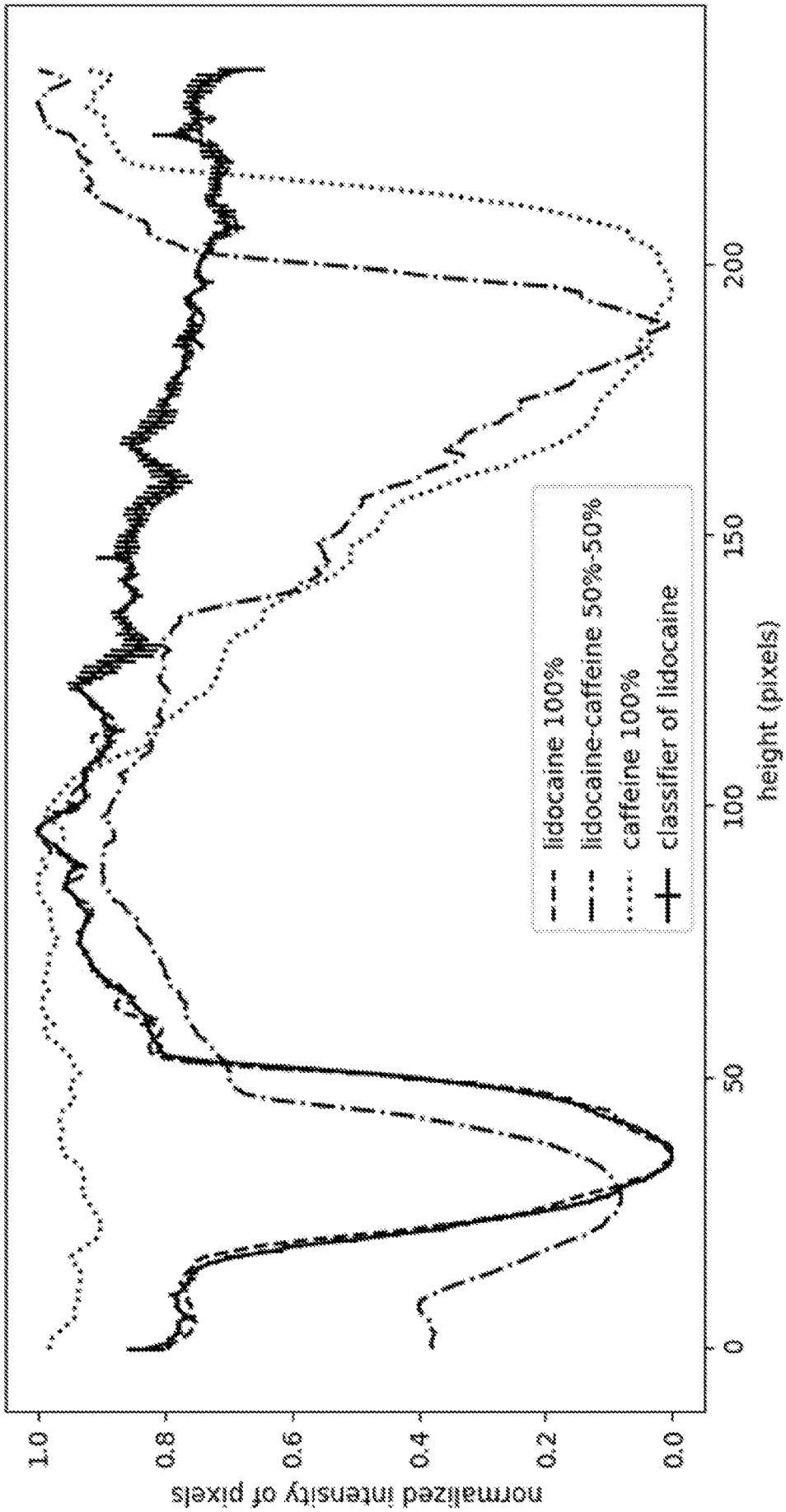

normalized intensity of pixels
0.0
0.2
0.4
0.6
0.8
1.0
0
50
100
150
200
height (pixels)
lidocaine 100%
lidocaine-caffeine 50%-50%
caffeine 100%
classifier of lidocaine

FIG. 23

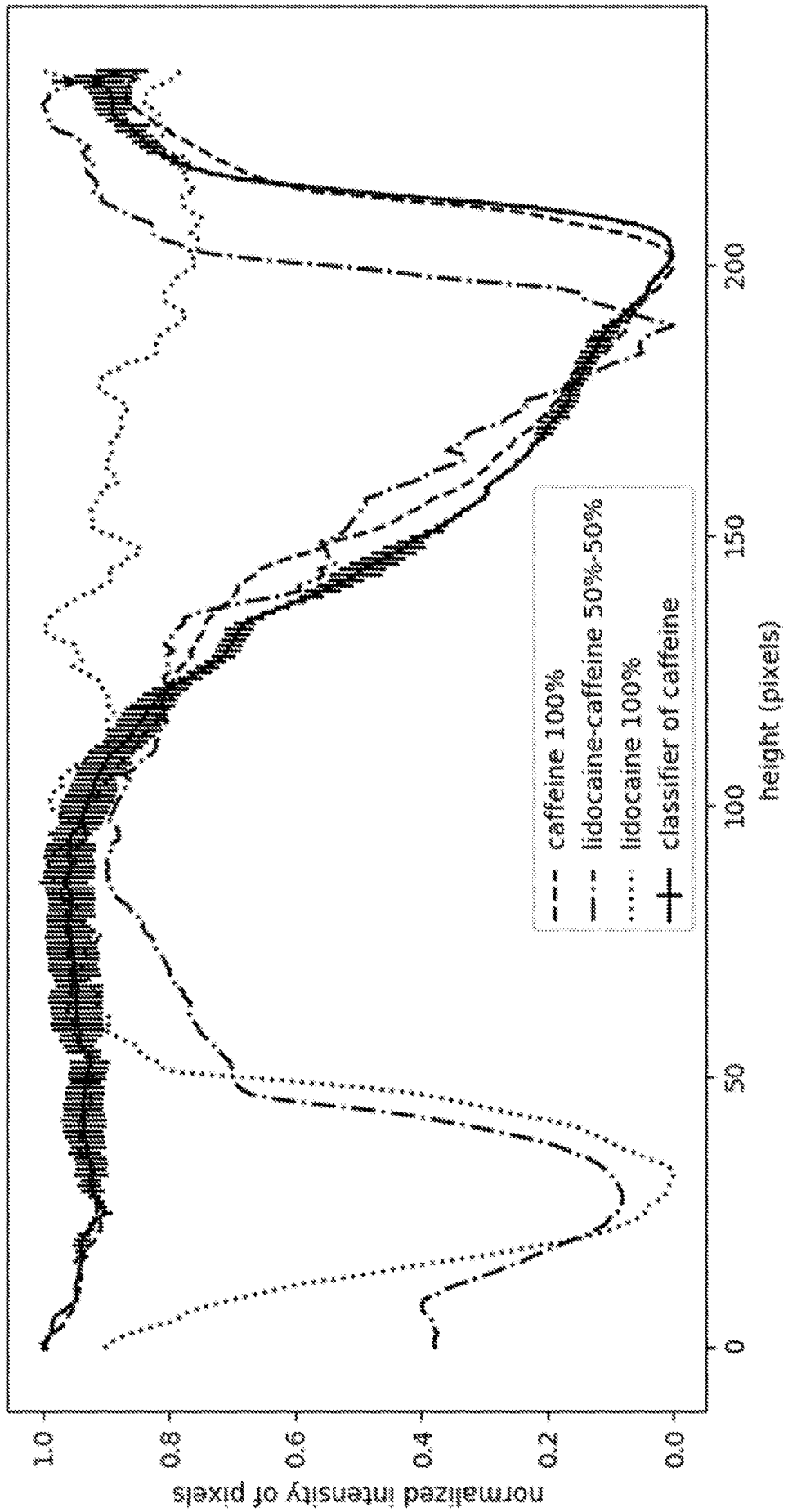

normalized intensity of pixels
0.0
0.2
0.4
0.6
0.8
1.0
0
50
100
150
200
height (pixels)
caffeine 100%
lidocaine-caffeine 50%-50%
lidocaine 100%
classifier of caffeine

FIG. 24

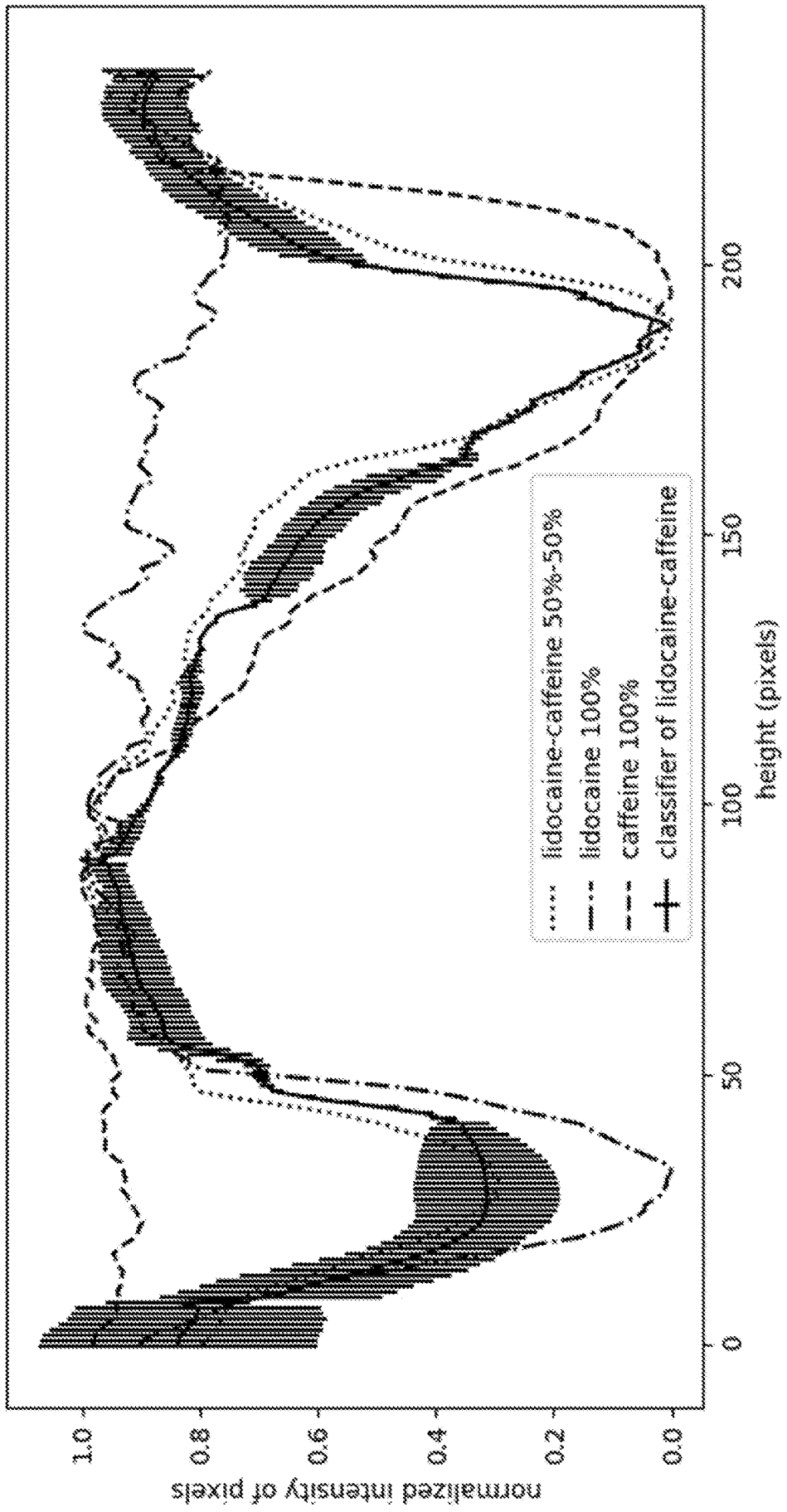

normalized intensity of pixels
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
height (pixels)
lidocaine-caffeine 50%-50%
lidocaine 100%
caffeine 100%
classifier of lidocaine-caffeine

FIG. 25

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 20/22924

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☒ Claims Nos.: 4-61
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 20/22924

A. CLASSIFICATION OF SUBJECT MATTER

IPC - B03C 1/00; B60L 13/04; G01N 27/72 (2020.01)

CPC - B03C 1/32; B03C 1/002; B60L 13/04; B60L 13/10; G01N 27/72

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
See Search History document

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	MIRICA et al, 'Magnetic Levitation in the Analysis of Foods and Water', Journal of Agricultural and Food Chemistry, volume 58, number 11, 13 May 2010 (13.05.2010), pg 6565-6569 and associated Supporting Information.	1-3
A	US 2015/0135829 A1 (PRESIDENT AND FELLOWS OF HARVARD COLLEGE), 21 May 2015 (21.05.2015), entire document.	1-3
A	US 2014/0123461 A1 (WHITESIDS et al), 8 May 2014 (08.05.2014), entire document.	1-3
A	US 6,902,065 B2 (KIMURA et al), 7 June 2005 (07.06.2005), entire document.	1-3
A	US 4,508,625 A (GRAHAM), 2 April 1985 (02.04.1985), entire document.	1-3

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"D" document cited by the applicant in the international application
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 May 2020	10 JUN 2020
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Authorized officer Lee Young Telephone No. PCT Helpdesk: 571-272-4300