

L-ORNITHINE PHENYL ACETATE AND METHODS OF MAKING THEREOF**CROSS-REFERENCE TO RELATED APPLICATIONS**

[0001] This application claims the benefit of priority of U.S. Provisional Application No. 61/166,676, filed April 3, 2009. The priority document is hereby incorporated by reference in its entirety.

BACKGROUNDField

[0002] The present application relates to the fields of pharmaceutical chemistry, biochemistry, and medicine. In particular, it relates to L-ornithine phenyl acetate salts and methods of making and using the same.

Description

[0003] Hyperammonemia is a hallmark of liver disease and is characterized by an excess of ammonia in the bloodstream. Hepatic encephalopathy is a primary clinical consequence of progressive hyperammonemia and is a complex neuropsychiatric syndrome, which may complicate acute or chronic hepatic failure. It is characterized by changes in mental state including a wide range of neuropsychiatric symptoms ranging from minor signs of altered brain function to overt psychiatric and/or neurological symptoms, or even deep coma. The accumulation of unmetabolized ammonia has been considered as the main factor involved in the pathogenesis of hepatic encephalopathy, but additional mechanisms may be associated.

[0004] L-Ornithine monohydrochloride and other L-ornithine salts are available for their use in the treatment of hyperammonemia and hepatic encephalopathy. For example, U.S. Publication No. 2008/0119554, which is hereby incorporated by reference in its entirety, describes compositions of L-ornithine and phenyl acetate for the treatment of hepatic encephalopathy. L-ornithine has been prepared by enzymatic conversion methods. For example, U.S. Patent Nos. 5,405,761 and 5,591,613, both of which are hereby incorporated by reference in their entirety, describe enzymatic conversion of arginine to form L-ornithine salts. Sodium phenyl acetate is commercially available, and also available as an injectable solution for the treatment of acute hyperammonemia. The injectable solution is marketed as AMMONUL.

[0005] Although salt forms may exhibit improved degradation properties, certain salts, particularly sodium or chloride salts, may be undesirable when treating patients having diseases associated with the liver disease, such as hepatic encephalopathy. For example, a high sodium intake may be dangerous for cirrhotic patients prone to ascites, fluid overload and electrolyte imbalances. Similarly, certain salts are difficult to administer intravenously because of an increased osmotic pressure, i.e., the solution is hypertonic. High concentrations of excess salt may require diluting large volumes of solution for intravenous administration which, in turn, leads to excessive fluid overload. Accordingly, there exists a need for the preparation of L-ornithine and phenyl acetate salts which are favorable for the treatment of hepatic encephalopathy or other conditions where fluid overload and electrolyte imbalance are prevalent.

SUMMARY

[0006] Some embodiments disclosed herein include a composition comprising a crystalline form of L-ornithine phenyl acetate.

[0007] In some embodiments, the crystalline form exhibits an X-ray powder diffraction pattern comprising at least one characteristic peak, wherein said characteristic peak is selected from the group consisting of approximately 6.0°, 13.9°, 14.8°, 17.1°, 17.8° and 24.1° 2 θ . In some embodiments, the crystalline form exhibits an X-ray powder diffraction pattern comprising at least three characteristic peaks, wherein said characteristic peaks are selected from the group consisting of approximately 6.0°, 13.9°, 14.8°, 17.1°, 17.8° and 24.1° 2 θ . In some embodiments, the crystalline form exhibits an X-ray powder diffraction pattern comprising characteristic peaks at approximately 6.0°, 13.9°, 14.8°, 17.1°, 17.8° and 24.1° 2 θ .

[0008] In some embodiments, the crystalline form has a melting point of about 202° C. In some embodiments, the crystalline form exhibits a single crystal X-ray crystallographic analysis with crystal parameters approximately equal to the following: unit cell dimensions: $a=6.594(2)$ Å, $b=6.5448(18)$ Å, $c=31.632(8)$ Å, $\alpha=90^\circ$, $\beta=91.12(3)^\circ$, $\gamma=90^\circ$; Crystal System: Monoclinic; and Space Group: $P2_1$. In some embodiments, the crystalline form is represented by the formula $[C_5H_{13}N_2O_2][C_8H_7O_2]$.

[0009] Some embodiments have the crystalline form exhibit an X-ray powder diffraction pattern comprising at least one characteristic peak, wherein said characteristic peak is selected from the group consisting of approximately 4.9°, 13.2°, 17.4°, 20.8° and

24.4° 2 θ . In some embodiments, the crystalline form exhibits an X-ray powder diffraction pattern comprising at least three characteristic peaks, wherein said characteristic peaks are selected from the group consisting of approximately 4.9°, 13.2°, 17.4°, 20.8° and 24.4° 2 θ . In some embodiments, the crystalline form exhibits an X-ray powder diffraction pattern comprising characteristic peaks at approximately 4.9°, 13.2°, 17.4°, 20.8° and 24.4° 2 θ .

[0010] Some embodiments have the crystalline form comprising water and/or ethanol molecules. In some embodiments, the crystalline form comprises about 11% by weight of said molecules as determined by thermogravimetric analysis. In some embodiments, the crystalline form is characterized by differential scanning calorimetry as comprising an endotherm at about 35° C. In some embodiments, the crystalline has a melting point at about 203° C.

[0011] Some embodiments have the crystalline form exhibiting a single crystal X-ray crystallographic analysis with crystal parameters approximately equal to the following: unit cell dimensions: $a=5.3652(4)$ Å, $b=7.7136(6)$ Å, $c=20.9602(18)$ Å, $\alpha=90^\circ$, $\beta=94.986(6)^\circ$, $\gamma=90^\circ$; Crystal System: Monoclinic; and Space Group: $P2_1$. In some embodiments, the crystalline form is represented by the formula $[C_5H_{13}N_2O_2][C_8H_7O_2]EtOH.H_2O$.

[0012] Some embodiments have the crystalline form exhibiting an X-ray powder diffraction pattern comprising at least one characteristic peak, wherein said characteristic peak is selected from the group consisting of approximately 5.8°, 14.1°, 18.6°, 19.4°, 22.3° and 24.8° 2 θ . In some embodiments, the crystalline form exhibits an X-ray powder diffraction pattern comprising at least three characteristic peaks, wherein said characteristic peaks are selected from the group consisting of approximately 5.8°, 14.1°, 18.6°, 19.4°, 22.3° and 24.8° 2 θ . In some embodiments, the crystalline form exhibits an X-ray powder diffraction pattern comprising characteristic peaks at approximately 5.8°, 14.1°, 18.6°, 19.4°, 22.3° and 24.8° 2 θ .

[0013] In some embodiments, the crystalline form is characterized by differential scanning calorimetry as comprising an endotherm at about 40° C. In some embodiments, the crystalline form comprises a melting point at about 203° C.

[0014] In some embodiments, the crystalline form exhibits an X-ray powder diffraction pattern comprising at least one characteristic peak, wherein said characteristic

peak is selected from the group consisting of approximately 13.7°, 17.4°, 19.8°, 20.6° and 23.7° 2 θ . In some embodiments, the crystalline form exhibits an X-ray powder diffraction pattern comprising at least three characteristic peaks, wherein said characteristic peak is selected from the group consisting of approximately 13.7°, 17.4°, 19.8°, 20.6° and 23.7° 2 θ . In some embodiments, the crystalline form exhibits an X-ray powder diffraction pattern comprising characteristic peaks at approximately 13.7°, 17.4°, 19.8°, 20.6° and 23.7° 2 θ .

[0015] In some embodiments, the crystalline form is characterized by differential scanning calorimetry as comprising an endotherm at about 174° C. In some embodiments, the crystalline form has a melting point of about 196° C. In some embodiments, the crystalline form comprises a pharmaceutically acceptable carrier.

[0016] Some embodiments disclosed herein have a composition comprising: at least about 50% by weight of a crystalline form of L-ornithine phenyl acetate salt and at least about 0.01% by weight benzoic acid or a salt thereof.

[0017] In some embodiments, the composition comprises at least about 0.10% by weight benzoic acid or a salt thereof. In some embodiments, the composition comprises no more than 5% by weight benzoic acid or a salt thereof. In some embodiments, the composition comprises no more than 1% by weight benzoic acid or a salt thereof.

[0018] In some embodiments, the composition further comprises at least 10 ppm silver. In some embodiments, comprises at least 20 ppm silver. In some embodiments, the composition further comprises at least 25 ppm silver. In some embodiments, comprises no more than 600 ppm silver. In some embodiments, composition comprises no more than 100 ppm silver. In some embodiments, the composition comprises no more than 65 ppm silver.

[0019] In some embodiments, about 50 mg/mL of the composition in water is isotonic with body fluids. In some embodiments, the isotonic solution has an osmolality in the range of about 280 to about 330 mOsm/kg.

[0020] In some embodiments, the composition has a density in the range of about 1.1 to about 1.3 kg/m³.

[0021] Some embodiments disclosed herein include a process for making L-ornithine phenyl acetate salt comprising: intermixing an L-ornithine salt, a benzoate salt

and a solvent to form an intermediate solution; intermixing phenyl acetate with said intermediate solution; and isolating a composition comprising at least 70% crystalline L-ornithine phenyl acetate by weight.

[0022] In some embodiments, the process comprises removing at least a portion of a salt from said intermediate solution before intermixing the phenyl acetate, wherein said salt is not an L-ornithine salt. In some embodiments, the process comprises adding hydrochloric acid before removing at least a portion of the salt.

[0023] In some embodiments, intermixing the L-ornithine, the benzoate salt and the solvent comprises: dispersing the L-ornithine salt in water to form a first solution; dispersing the benzoate salt in DMSO to form a second solution; and intermixing said first solution and said second solution to form said solution.

[0024] In some embodiments, the composition comprises at least about 0.10% by weight benzoate salt. In some embodiments, composition comprises no more than 5% by weight benzoate salt. In some embodiments, composition comprises no more than 1% by weight benzoate salt.

[0025] In some embodiments, the L-ornithine salt is L-ornithine hydrochloride. In some embodiments, the benzoate salt is silver benzoate.

[0026] In some embodiments, the composition comprises at least 10 ppm silver. In some embodiments, composition comprises at least 20 ppm silver. In some embodiments, the composition comprises at least 25 ppm silver. In some embodiments, the composition comprises no more than 600 ppm silver. In some embodiments, the composition comprises no more than 100 ppm silver. In some embodiments, the composition comprises no more than 65 ppm silver.

[0027] In some embodiments, the phenyl acetate is in an alkali metal salt. In some embodiments, the alkali metal salt is sodium phenyl acetate.

[0028] In some embodiments, the composition comprises no more than 100 ppm sodium. In some embodiments, the composition comprises no more than 20 ppm sodium.

[0029] In some embodiments, the L-ornithine is in a halide salt. In some embodiments, the halide salt is L-ornithine hydrochloride.

[0030] In some embodiments, the composition comprises no more than 0.1% by weight chloride. In some embodiments, the composition comprises no more than 0.01% by weight chloride.

[0031] Some embodiments disclosed herein include a composition obtained by any of the processes disclosed herein.

[0032] Some embodiments disclosed herein include a process for making L-ornithine phenyl acetate salt comprising: increasing the pH value of a solution comprising an L-ornithine salt at least until an intermediate salt precipitates, wherein said intermediate salt is not an L-ornithine salt; isolating the intermediate salt from said solution; intermixing phenyl acetic acid with said solution; and isolating L-ornithine phenyl acetate salt from said solution.

[0033] In some embodiments, the pH value is increased to at least 8.0. In some embodiments, the pH value is increased to at least 9.0. In some embodiments, increasing the pH value comprises adding a pH modifier selected from the group consisting of sodium hydroxide, potassium hydroxide, sodium methoxide, potassium t-butoxide, sodium carbonate, calcium carbonate, dibutylamine, tryptamine, sodium hydride, calcium hydride, butyllithium, ethylmagnesium bromide or combinations thereof.

[0034] Some embodiments disclosed herein include a method of treating or ameliorating hyperammonemia in a subject by administering a therapeutically effective amount of a crystalline form of L-ornithine phenyl acetate salt.

[0035] In some embodiments, the crystalline form is administered orally.

[0036] In some embodiments, the crystalline form is selected from the group consisting of Form I, Form II, Form III, Form V, wherein: Form I exhibits an X-ray powder diffraction pattern having characteristic peaks at approximately 4.9°, 13.2°, 17.4°, 20.8° and 24.4° 2 θ ; Form II exhibits an X-ray powder diffraction pattern having characteristic peaks at approximately 6.0°, 13.9°, 14.8°, 17.1°, 17.8° and 24.1° 2 θ ; Form III exhibits an X-ray powder diffraction pattern having characteristic peaks at approximately 5.8°, 14.1°, 18.6°, 19.4°, 22.3° and 24.8° 2 θ ; and Form V exhibits an X-ray powder diffraction pattern having characteristic peaks at approximately 13.7°, 17.4°, 19.8°, 20.6° and 23.7° 2 θ .

[0037] In some embodiments, the crystalline form is Form I. In some embodiments, the crystalline form is Form II. In some embodiments, the crystalline form is Form III. In some embodiments, the crystalline form is Form V.

[0038] In some embodiments, the at least two crystalline forms selected from the group consisting of Form I, Form II, Form III and Form V, are administered. In some embodiments, the at least two crystalline forms are administered at about the same time.

[0039] In some embodiments, the crystalline form is administered from 1 to 3 times daily. In some embodiments, the therapeutically effective amount is in the range of about 500 mg to about 50 g.

[0040] In some embodiments, the subject is identified as having hepatic encephalopathy. In some embodiments, the subject is identified as having hyperammonemia.

[0041] Some embodiments disclosed herein include a process for making L-ornithine phenyl acetate salt comprising: intermixing an L-ornithine salt, silver phenyl acetate and a solvent to form a solution, wherein the L-ornithine salt is an alkali metal salt; and isolating L-ornithine phenyl acetate from said solution.

[0042] Some embodiments disclosed herein include a method of treating or ameliorating hyperammonemia comprising intravenously administering a therapeutically effective amount of a solution comprising L-ornithine phenyl acetate, wherein said therapeutically effective amount comprises no more than 500 mL of said solution.

[0043] In some embodiments, the solution comprises at least about 25 mg/mL of L-ornithine phenyl acetate. In some embodiments, the solution comprises at least about 40 mg/mL of L-ornithine phenyl acetate. In some embodiments, the solution comprises no more than 300 mg/mL. In some embodiments, the solution is isotonic with body fluid.

[0044] Some embodiments disclosed herein include a method of compressing L-ornithine phenyl acetate, the method comprising applying pressure to a metastable form of L-ornithine phenyl acetate to induce a phase change.

[0045] In some embodiments, the metastable form is amorphous. In some embodiments, the metastable form exhibits an X-ray powder diffraction pattern comprising at least one characteristic peak, wherein said characteristic peak is selected from the group consisting of approximately 4.9°, 13.2°, 20.8° and 24.4° 2 θ .

[0046] In some embodiments, the pressure is applied for a predetermined time. In some embodiments, the predetermined time is about 1 second or less. In some embodiments, the pressure is at least about 500 psi.

[0047] In some embodiments, the phase change yields a composition having a density in the range of about 1.1 to about 1.3 kg/m³ after applying the pressure.

[0048] In some embodiments, the phase change yields a composition exhibiting an X-ray powder diffraction pattern comprising at least one characteristic peak, wherein said characteristic peak is selected from the group consisting of approximately 6.0°, 13.9°, 14.8°, 17.1°, 17.8° and 24.1° 2 θ .

[0049] Some embodiments disclosed herein include a composition obtained by applying pressure to a metastable form of L-ornithine phenyl acetate to induce a phase change.

BRIEF DESCRIPTION OF THE DRAWINGS

[0050] FIGURE 1 is an X-ray powder diffraction pattern of Form I.

[0051] FIGURE 2 shows differential scanning calorimetry results for Form I.

[0052] FIGURE 3 shows thermogravimetric gravimetric/differential thermal analysis of Form I.

[0053] FIGURE 4 shows the ¹H nuclear magnetic resonance spectrum obtained from a sample of Form I.

[0054] FIGURE 5 shows dynamic vapor sorption results for Form I.

[0055] FIGURE 6 is an X-ray powder diffraction pattern of Form II.

[0056] FIGURE 7 shows differential scanning calorimetry results for Form II.

[0057] FIGURE 8 shows thermogravimetric gravimetric/differential thermal analysis of Form II.

[0058] FIGURE 9 shows the ¹H nuclear magnetic resonance spectrum obtained from a sample of Form II.

[0059] FIGURE 10 shows dynamic vapor sorption results for Form II.

[0060] FIGURE 11 is an X-ray powder diffraction pattern of Form III.

[0061] FIGURE 12 shows differential scanning calorimetry results for Form III.

[0062] FIGURE 13 shows thermogravimetric gravimetric/differential thermal analysis of Form III.

[0063] FIGURE 14 shows the ¹H nuclear magnetic resonance spectrum obtained from a sample of Form III.

[0064] FIGURE 15 shows dynamic vapor sorption results for Form III.

[0065] FIGURE 16 is an X-ray powder diffraction pattern of Form V.

[0066] FIGURE 17 shows differential scanning calorimetry results for Form V.

[0067] FIGURE 18 shows thermogravimetric gravimetric/differential thermal analysis of Form V.

[0068] FIGURE 19 shows the ^1H nuclear magnetic resonance spectrum obtained from a sample of Form V.

[0069] FIGURE 20 shows dynamic vapor sorption results for Form V.

[0070] FIGURE 21 shows the ^1H nuclear magnetic resonance spectrum obtained from a sample of L-ornithine benzoate.

[0071] FIGURE 22 shows the ^1H nuclear magnetic resonance spectrum obtained from a sample of L-ornithine phenyl acetate.

DETAILED DESCRIPTION

[0072] Disclosed herein are methods of making L-ornithine phenyl acetate salts, and in particular, crystalline forms of said salt. These methods permit large-scale production of pharmaceutically acceptable forms of L-ornithine phenyl acetate using economical processes. Moreover, crystalline forms of L-ornithine phenyl acetate, including Forms I, II, III and V are also disclosed. The L-ornithine phenyl acetate salts permit intravenous administration with negligible concomitant sodium load, and therefore minimize the amount of i.v. fluid that is required.

[0073] The present application relates to new crystalline forms of L-ornithine phenyl acetate salts, as well as methods of making and using L-ornithine phenyl acetate salts. The salt advantageously exhibits long-term stability without significant amounts of sodium or chloride. As a result, L-ornithine phenyl acetate is expected to provide an improved safety profile compared to other salts of L-ornithine and phenyl acetate. Also, L-ornithine phenyl acetate exhibits lower tonicity compared to other salts, and therefore can be administered intravenously at higher concentrations. Accordingly, L-ornithine phenyl acetate is expected to provide significant clinical improvements for the treatment of hepatic encephalopathy.

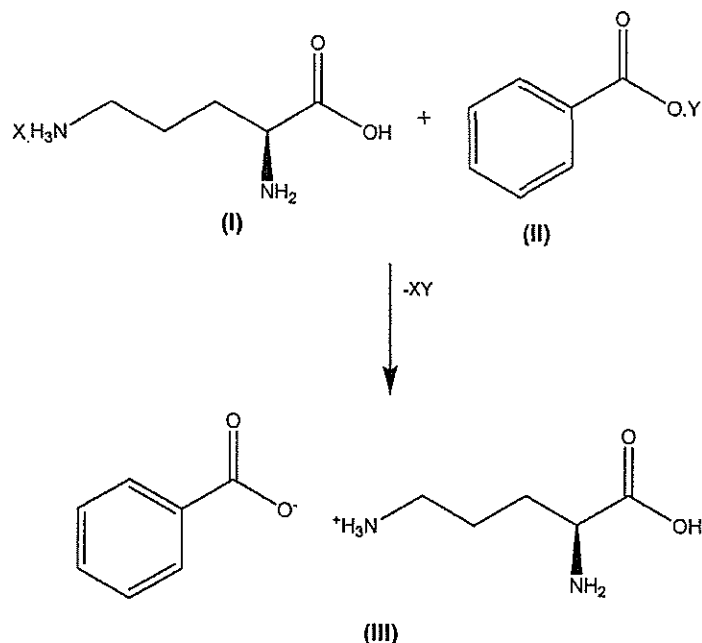
[0074] The present application also relates to various polymorphs of L-ornithine phenyl acetate. The occurrence of different crystal forms (polymorphism) is a property of some molecules and molecular complexes. Salt complexes, such as L-ornithine phenyl acetate, may give rise to a variety of solids having distinct physical

properties like melting point, X-ray diffraction pattern, infrared absorption fingerprint and NMR spectrum. The differences in the physical properties of polymorphs result from the orientation and intermolecular interactions of adjacent molecules (complexes) in the bulk solid. Accordingly, polymorphs can be distinct solids sharing the same active pharmaceutical ingredient yet having distinct advantageous and/or disadvantageous physico-chemical properties compared to other forms in the polymorph family.

Method of Making L-Ornithine Phenyl Acetate Salt

[0075] Some embodiments disclosed herein include a method of making L-ornithine phenyl acetate salt. L-Ornithine phenyl acetate may be produced, for example, through an intermediate salt, such as L-ornithine benzoate. As shown in Scheme 1, an L-ornithine salt of Formula I can be reacted with a benzoate salt of Formula II to obtain the intermediate L-ornithine benzoate.

Scheme 1



[0076] Various salts of L-ornithine may be used in the compound of Formula I, and therefore X in Formula I can be any ion capable of forming a salt with L-ornithine other than benzoic acid or phenyl acetic acid. X can be a monoatomic anion, such as, but not limited to, a halide (*e.g.*, fluoride, chloride, bromide, and iodide). X can also be a polyatomic anion, such as, but not limited to, acetate, aspartate, formate, oxalate, bicarbonate, carbonate, bitrate, sulfate, nitrate, isonicotinate, salicylate, citrate, tartrate,

pantothenate, bitartrate, ascorbate, succinate, maleate, gentisinate, fumarate, gluconate, glucaronate, saccharate, formate, glutamate, methanesulfonate, ethanesulfonate, benzensulfonate, p-toluenesulfonate, pamoate (*i.e.*, 1,1'-methylene-bis-(2-hydroxy-3-naphthoate), phosphate and the like. In some embodiments, X is a monovalent ion. In some embodiments, X is chloride.

[0077] Similarly, the benzoate salt of Formula II is not particularly limited, and therefore Y in Formula II can be any appropriate ion capable of forming a salt with benzoic acid. In some embodiments, Y can be a monoatomic cation, such as an alkali metal ion (*e.g.*, Li^+ , Na^+ , and K^+) and other monovalent ions (*e.g.*, Ag^+). Y may also be a polyatomic cation, such as ammonium, L-arginine, diethylamine, choline, ethanolamine, 1H-imidazole, trolamine, and the like. In some embodiments, Y is an inorganic ion. In some embodiments, Y is silver.

[0078] Many other possible salts of L-ornithine and benzoic acid may be used for the compounds of Formulae I and II, respectively, and can readily be prepared by those skilled in the art. See, for example, Bighley L.D., et al., "Salt forms of drugs and absorption," In: Swarbrick J., Horlan J.C., eds. Encyclopedia of pharmaceutical technology, Vol. 12. New York: Marcel Dekker, Inc. pp. 452-499, which is hereby incorporated by reference in its entirety.

[0079] The intermediate L-ornithine benzoate (*i.e.*, Formula III) can be prepared by intermixing solutions including compounds of Formulae I and II. As an example, the compounds of Formulae I and II may be separately dissolved in water and dimethyl sulfoxide (DMSO), respectively. The two solutions may then be intermixed so that the L-ornithine and benzoic acid react to form the salt of Formula III. Alternatively, the two salt compounds can be directly dissolved into a single solution. In some embodiments, L-ornithine and benzoic acid are dissolved in separate solvents, and subsequently intermixed. In some embodiments, L-ornithine is dissolved in an aqueous solution, benzoic acid is dissolved in an organic solvent, and the L-ornithine and benzoic acid solutions are subsequently intermixed.

[0080] Non-limiting examples of solvents which may be used when intermixing L-ornithine and benzoate salts include acetonitrile, dimethylsulfoxide (DMSO), cyclohexane, ethanol, acetone, acetic acid, 1-propanol, dimethylcarbonate, N-methyl-2-pyrrolidone (NMP), ethyl acetate (EtOAc), toluene, isopropyl alcohol (IPA), diisopropyl ether, nitromethane, water, 1,4 dioxane, diethyl ether, ethylene glycol,

methyl acetate (MeOAc), methanol, 2-butanol, cumene, ethyl formate, isobutyl acetate, 3-methyl-1-butanol, anisole, and combinations thereof. In some embodiments, the L-ornithine benzoate solution includes water. In some embodiments, the L-ornithine benzoate solution includes DMSO.

[0081] Upon intermixing L-ornithine and benzoate salts, counterions X and Y may form a precipitate that can be removed from the intermixed solution using known methods, such as filtration, centrifugation, and the like. In some embodiments, X is chloride, Y is silver, and the reaction produces a precipitate having AgCl. Although Scheme 1 shows the compounds of Formulae I and II as salts, it is also within the scope of the present application to intermix the free base of L-ornithine and benzoic acid to form the intermediate of L-ornithine benzoate. Consequently, forming and isolating the precipitate is optional.

[0082] The relative amount of L-ornithine and benzoate salts that are intermixed is not limited; however the molar ratio of L-ornithine to benzoic acid may optionally be in the range of about 10:90 and 90:10. In some embodiments, the molar ratio of L-ornithine benzoate can be in the range of about 30:70 and 70:30. In some embodiments, the molar ratio of L-ornithine to benzoate can be in the range of about 40:60 and 60:40. In some embodiments, the molar ratio of L-ornithine to benzoate is about 1:1.

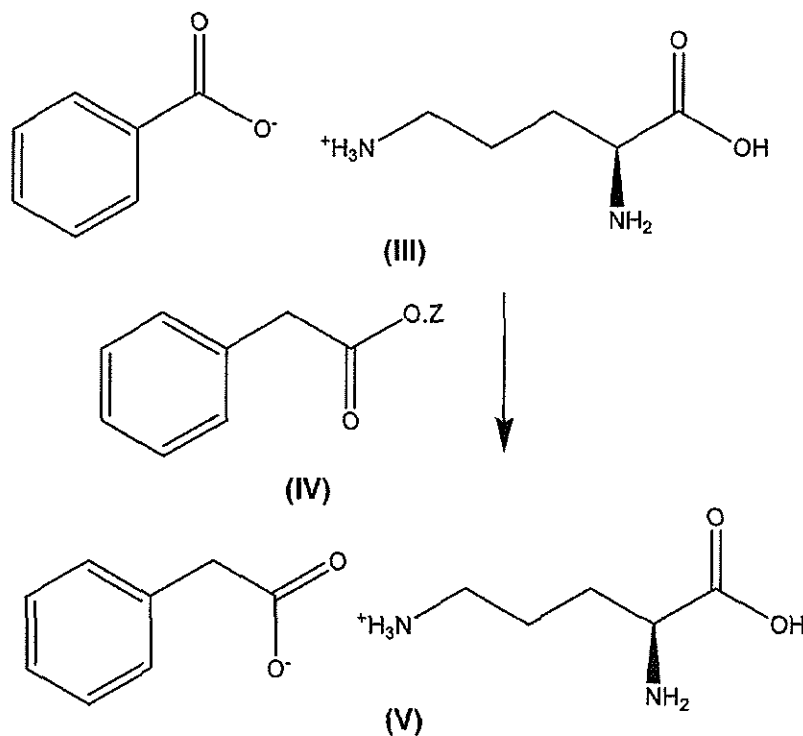
[0083] In embodiments where X and Y are both inorganic ions (e.g., X and Y are chloride and silver, respectively), additional amounts of X-containing salt may be added to encourage further precipitation of the counterion Y. For example, if X is chloride and Y is silver, the molar ratio of L-ornithine hydrochloride to silver benzoate may be greater than 1:1 so that an excess of chloride is present relative to silver. Accordingly, in some embodiments, the molar ratio of L-ornithine to benzoic acid is greater than about 1:1. Nevertheless, the additional chloride salt is not required to be derived from an L-ornithine salt (e.g., L-ornithine hydrochloride). For example, dilute solutions of hydrochloric acid may be added to the solution to further remove silver. Although it is not particularly limited when the additional X-containing salt is added, it is preferably added before the AgCl is initially isolated.

[0084] As shown in Scheme 2, the L-ornithine benzoate can be reacted with a phenyl acetate salt of Formula IV to form L-ornithine phenyl acetate. For example, sodium phenyl acetate can be intermixed with a solution of L-ornithine benzoate to form

L-ornithine phenyl acetate. Various salts of phenyl acetate may be used, and therefore Z in Formula IV can be any cation capable of forming a salt with phenyl acetate other than benzoic acid or L-ornithine. In some embodiments, Z can be a monoatomic cation, such as an alkali metal ion (*e.g.*, Li^+ , Na^+ , and K^+) and other monovalent ions (*e.g.*, Ag^+). Z may also be a polyatomic cation, such as ammonium, L-arginine, diethylamine, choline, ethanolamine, 1H-imidazole, trolamine, and the like. In some embodiments, Z is an inorganic ion. In some embodiments, Z is sodium.

[0085] The relative amount of L-ornithine and phenyl acetate salts that are intermixed is also not limited; however the molar ratio of L-ornithine to phenyl acetate may optionally be in the range of about 10:90 and 90:10. In some embodiments, the molar ratio of L-ornithine to phenyl acetate can be in the range of about 30:70 and 30:70. In some embodiments, the molar ratio of L-ornithine to phenyl acetate can be in the range of about 40:60 and 60:40. In some embodiments, the molar ratio of L-ornithine to benzoic acid is about 1:1.

Scheme 2

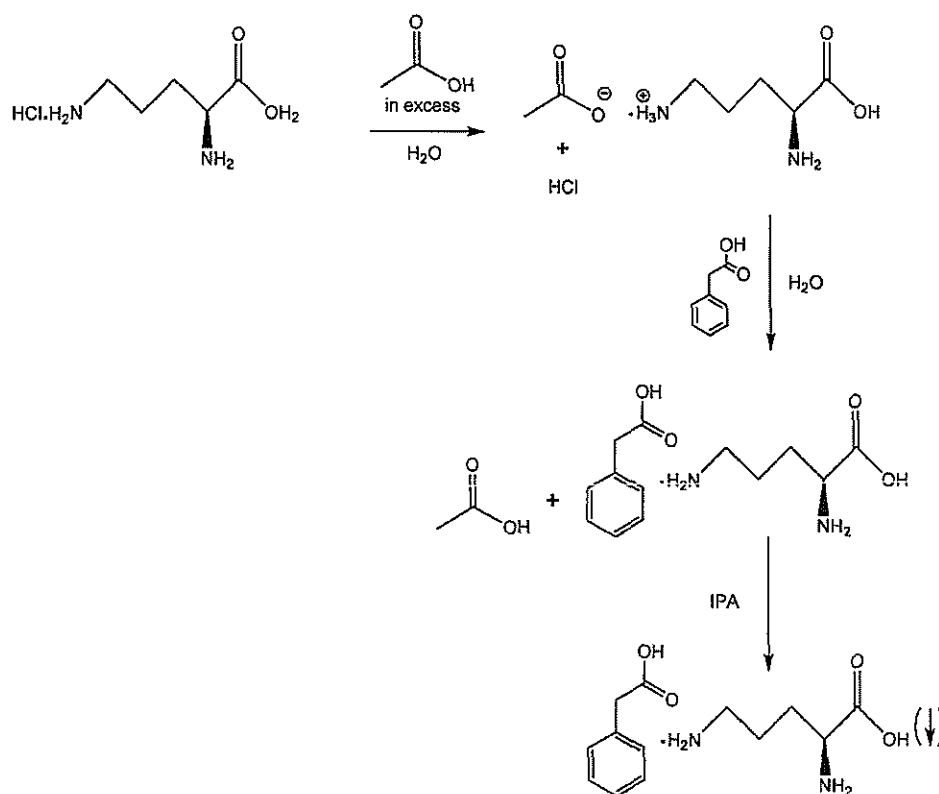


[0086] The L-ornithine phenyl acetate of Formula V may then be isolated from solution using known techniques. For example, by evaporating any solvent until the L-ornithine phenyl acetate crystallizes, or alternatively by the adding an anti-solvent

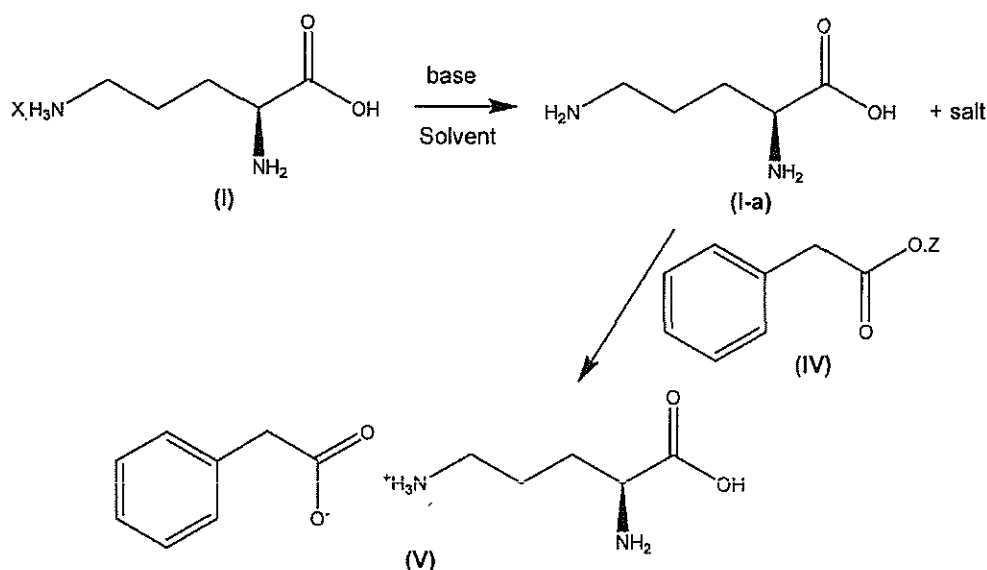
miscible in the L-ornithine phenyl acetate solution until the L-ornithine phenyl acetate precipitates from solution. Another possible means for isolating the L-ornithine phenyl acetate is to adjust the temperature of the solution (*e.g.*, lower the temperature) until the L-ornithine phenyl acetate precipitates. As will be discussed in further detail in a later section, the method of isolating the L-ornithine phenyl acetate affects the crystalline form that is obtained.

[0087] The isolated L-ornithine phenyl acetate may be subjected to various additional processing, such as drying and the like. In some embodiments, L-ornithine phenyl acetate may be subsequently intermixed with a dilute HCl solution to precipitate residual silver. The L-ornithine phenyl acetate may again be isolated from solution using similar methods disclosed above.

[0088] As would be appreciated by a person of ordinary, guided by the teachings of the present application, L-ornithine phenyl acetate may similarly be prepared using an intermediate salt other than L-ornithine benzoate. Thus, for example, L-ornithine, or a salt thereof (*e.g.*, L-ornithine hydrochloride), can be intermixed with a solution having acetic acid. L-Ornithine acetate may then be intermixed with phenyl acetic acid, or a salt thereof (*e.g.*, sodium phenyl acetate), to obtain L-ornithine phenyl acetate. Scheme 4 illustrates an exemplary process of forming L-ornithine phenyl acetate using L-ornithine acetate as an intermediate salt. In some embodiments, the intermediate salt can be a pharmaceutically acceptable salt of L-ornithine. For example, the intermediate L-ornithine salt can be an acetate, aspartate, formate, oxalate, bicarbonate, carbonate, bitrate, sulfate, nitrate, isonicotinate, salicylate, citrate, tartrate, pantothenate, bitartrate, ascorbate, succinate, maleate, gentisinate, fumarate, gluconate, glucuronate, saccharate, formate, benzoate, glutamate, methanesulfonate, ethanesulfonate, benzensulfonate, p-toluenesulfonate, pamoate (*i.e.*, 1,1'-methylene-bis-(2-hydroxy-3-naphthoate) or phosphate. The free acid of the intermediate is preferably a weaker acid relative to phenyl acetic acid. In some embodiments, the intermediate is an L-ornithine salt with an anion component that exhibits a pK_a value that is higher than the pK_a value of phenyl acetic acid. As an example, for L-ornithine acetate, acetic acid and phenyl acetic acid exhibit pK_a values of about 4.76 and 4.28, respectively.

Scheme 3

[0089] L-Ornithine phenyl acetate may also be prepared, in some embodiments, without forming an intermediate salt, such as L-ornithine benzoate. Scheme 4 illustrates an exemplary process for preparing L-ornithine phenyl acetate without an intermediate salt. A pH modifier may be added to a solution of L-ornithine salt (*e.g.*, as illustrated in Scheme 4 by the compound of Formula I) until a salt precipitates from solution, where the salt is not an L-ornithine salt. As an example, sodium methoxide (NaOMe) can be added to a solution of L-ornithine hydrochloride until sodium chloride precipitates from solution to leave a free base of L-ornithine. The precipitate may optionally be isolated from solution using known techniques, such as filtration, centrifugation, and the like. The free base of L-ornithine (*e.g.*, as illustrated in Scheme 4 by the compound of Formula I-a) may be intermixed with phenyl acetic acid, or a salt thereof (*e.g.*, as illustrated in Scheme 4 by the compound of Formula IV), to obtain L-ornithine phenyl acetate. The L-ornithine phenyl acetate of Formula V may then be isolated as previously described.

Scheme 4

[0090] A pH modifier can include a basic compound, or anhydrous precursor thereof, and/or a chemically protected base. Non-limiting examples of pH modifiers include sodium hydroxide, potassium hydroxide, sodium methoxide, potassium t-butoxide, sodium carbonate, calcium carbonate, dibutylamine, tryptamine, sodium hydride, calcium hydride, butyllithium, ethylmagnesium bromide and combinations thereof. Also, the amount of pH modifier to be added is not particularly limited; however the molar ratio of L-ornithine to pH modifier may optionally be in the range of about 10:90 and 90:10. In some embodiments, the molar ratio of L-ornithine to pH modifier can be in the range of about 30:70 and 70:30. In some embodiments, the molar ratio of L-ornithine to pH modifier can be in the range of about 40:60 and 60:40. In some embodiments, the molar ratio of L-ornithine to pH modifier is about 1:1. The pH modifier may, in some embodiments be added to adjust the pH value to at least about 8.0; at least about 9.0; or at least about 9.5.

[0091] Another process for forming L-ornithine phenyl acetate, in some embodiments, includes reacting an alkali metal salt of L-ornithine with a phenyl acetate salt. As an example, L-ornithine hydrochloride may be intermixed with silver phenyl acetate and a solvent. AgCl may then precipitate and is optionally isolated from the solution. The remaining L-ornithine phenyl acetate can also be isolated using known methods. This process can be completed using generally the same procedures and conditions outlined above. For example, the relative molar amounts of L-ornithine to

phenyl acetate can be 10:90 to 90:10; 30:70 to 70:30; 40:60 to 60:40; or about 1:1. Also, the L-ornithine phenyl acetate may be isolated by evaporating the solvent, adding an anti-solvent, and/or reducing the temperature.

Compositions of L-Ornithine Phenyl Acetate

[0092] Also disclosed herein are compositions of L-ornithine phenyl acetate. The compositions of the present application advantageously have low amounts of inorganic salts, particularly alkali metal salts and/or halide salts, and therefore are particularly suited for oral and/or intravenous administration to patients with hepatic encephalopathy. Meanwhile, these compositions may exhibit similar stability profiles compared to other salts (*e.g.*, mixtures of L-ornithine hydrochloride and sodium phenyl acetate). The compositions may, in some embodiments, be obtained by one of the processes disclosed in the present application. For example, any of the disclosed processes using L-ornithine benzoate as an intermediate may yield the compositions of the present application.

[0093] The compositions, in some embodiments, can include a crystalline form of L-ornithine phenyl acetate (*e.g.*, Forms I, II, III and/or V disclosed herein). In some embodiments, the composition may include at least about 20% by weight of a crystalline form of L-ornithine phenyl acetate (preferably at least about 50% by weight, and more preferably at least about 80% by weight). In some embodiments, the composition consists essentially of a crystalline form of L-ornithine phenyl acetate. In some embodiments, the composition includes a mixture of at least two (*e.g.*, two, three or four forms) of Forms I, II, III, and V.

[0094] The compositions, in some embodiments, include Form II. For example, the compositions may include at least about 20%; at least about 50%; at least about 90%; at least about 95%; or at least about 99% of Form II. Similarly, the compositions may also include, for example, Forms I, III or V. The compositions may optionally include at least about 20%; at least about 50%; at least about 90%; at least about 95%; or at least about 99% of Forms I, II, III and/or V.

[0095] Also within the scope of the present application are amorphous forms of L-ornithine phenyl acetate. Various methods are known in the art for preparing amorphous forms. For example, a solution of L-ornithine phenyl acetate may be dried under vacuum by lyophilization to obtain an amorphous composition. See P.C.T.

Application WO 2007/058634, which published in English and designates the U.S., and is hereby incorporated by reference for disclosing methods of lyophilization.

[0096] It is preferred that the composition have low amounts (if any) of alkali and halogen ions or salts, particular sodium and chloride. In some embodiments, the composition comprises no more than about 100 ppm of alkali metals (preferably no more than about 20 ppm, and most preferably no more than about 10 ppm). In some embodiments, the composition comprises no more than about 100 ppm of sodium (preferably no more than about 20 ppm, and most preferably no more than about 10 ppm). In some embodiments, the composition comprises no more than about 0.1% by weight of halides (preferably no more than about 0.01% by weight). In some embodiments, the composition comprises no more than about 0.1% by weight of chloride (preferably no more than about 0.01% by weight).

[0097] The reduced content of alkali metals and halides provides a composition suitable for preparing concentrated isotonic solutions. As such, these compositions can be more easily administered intravenously compared to, for example, administering mixtures of L-ornithine hydrochloride and sodium phenyl acetate. In some embodiments, an about 45 to about 55 mg/mL solution of L-ornithine phenyl acetate in water (preferably about 50 mg/mL) is isotonic with body fluids (*e.g.*, the solution exhibits an osmolality in the range of about 280 to about 330 mOsm/kg).

[0098] The compositions may also include residual amounts of the anion from an intermediate salt formed during the process of making the L-ornithine phenyl acetate composition. For example, some of the processes disclosed herein yield compositions having benzoic acid or a salt thereof. In some embodiments, the composition comprises at least about 0.01% by weight benzoic acid or a salt thereof (preferably at least about 0.05% by weight, and more preferably about 0.1% by weight). In some embodiments, the composition comprises no more than about 3% by weight benzoic acid or a salt thereof (preferably no more than about 1% by weight, and more preferably no more than about 0.5% by weight). In some embodiments, the composition includes a salt, or an acid thereof, in the range of about 0.01% to about 3% by weight (preferably about 0.1% to about 1%), wherein the salt is selected from acetate, aspartate, formate, oxalate, bicarbonate, carbonate, bitrate, sulfate, nitrate, isonicotinate, salicylate, citrate, tartrate, pantothenate, bitartrate, ascorbate, succinate, maleate, gentisinate, fumarate, gluconate, glucaronate, saccharate, formate, benzoate, glutamate, methanesulfonate, ethanesulfonate,

benzensulfonate, p-toluenesulfonate, pamoate (*i.e.*, 1,1'-methylene-bis-(2-hydroxy-3-naphthoate) or phosphate.

[0099] Similarly, a composition prepared using an acetate intermediate may have residual amounts of acetic acid or acetate. In some embodiments, the composition includes at least about 0.01% by weight acetic acid or acetate (preferably at least about 0.05% by weight, and more preferably about 0.1% by weight). In some embodiments, the composition includes no more than about 3% by weight acetic acid or acetate (preferably no more than about 1% by weight, and more preferably no more than about 0.5% by weight).

[0100] The compositions may also include low amounts of silver. Exemplary processes disclosed herein utilize, for example, silver benzoate, but still yield compositions with surprisingly low amounts of silver. Thus, in some embodiments, the composition includes no more than about 600 ppm silver (preferably no more than about 100 ppm, and more preferably no more than about 65 ppm). In some embodiments, the composition includes at least about 10 ppm silver (alternatively at least about 20 or 25 ppm silver).

Pharmaceutical Compositions

[0101] The compositions of L-ornithine phenyl acetate of the present application may also be formulated for administration to a subject (*e.g.*, a human). L-Ornithine phenyl acetate, and accordingly the compositions disclosed herein, may be formulated for administration with a pharmaceutically acceptable carrier or diluent. L-ornithine phenyl acetate may thus be formulated as a medicament with a standard pharmaceutically acceptable carrier(s) and/or excipient(s) as is routine in the pharmaceutical art. The exact nature of the formulation will depend upon several factors including the desired route of administration. Typically, L-ornithine phenyl acetate is formulated for oral, intravenous, intragastric, subcutaneous, intravascular or intraperitoneal administration.

[0102] The pharmaceutical carrier or diluent may be, for example, water or an isotonic solution, such as 5% dextrose in water or normal saline. Solid oral forms may contain, together with the active compound, diluents, *e.g.* lactose, dextrose, saccharose, cellulose, corn starch or potato starch; lubricants, *e.g.* silica, talc, stearic acid, magnesium or calcium stearate, and/or polyethylene glycols; binding agents, *e.g.* starches, gum arabic, gelatin, methylcellulose, carboxymethylcellulose or polyvinyl pyrrolidone; disaggregating

agents, e.g. starch, alginic acid, alginates or sodium starch glycolate; effervescing mixtures; dyestuffs; sweeteners; wetting agents, such as lecithin, polysorbates, laurylsulphates; and, in general, non-toxic and pharmacologically inactive substances used in pharmaceutical formulations. Such pharmaceutical preparations may be manufactured in known manners, for example, by means of mixing, granulating, tableting, sugar-coating, or film-coating processes.

[0103] Liquid dispersions for oral administration may be syrups, emulsions or suspensions. The syrups may contain as carriers, for example, saccharose or saccharose with glycerine and/or mannitol and/or sorbitol.

[0104] Suspensions and emulsions may contain a carrier, for example a natural gum, agar, sodium alginate, pectin, methylcellulose, carboxymethylcellulose, or polyvinyl alcohol. The suspensions or solutions for intramuscular injections may contain, together with L-ornithine phenyl acetate, a pharmaceutically acceptable carrier, e.g. sterile water, olive oil, ethyl oleate, glycols, e.g. propylene glycol, and if desired, a suitable amount of lidocaine hydrochloride.

[0105] The medicament may consist essentially of L-ornithine phenyl acetate and a pharmaceutically acceptable carrier. Such a medicament therefore contains substantially no other amino acids in addition to L-ornithine and phenyl acetate. Furthermore, such a medicament contains insubstantial amounts of other salts in addition to L-ornithine phenyl acetate.

[0106] Oral formulations may generally include dosages of L-ornithine phenyl acetate in the range of about 500 mg to about 100 g. Accordingly, in some embodiments, the oral formulation includes the L-ornithine phenyl acetate compositions disclosed herein in the range of about 500 mg to about 50 g. In some embodiments, the oral formulation is substantially free of alkali metal salts and halides (e.g., contains no more than trace amounts of alkali metal salts and halides).

[0107] Intravenous formulations may also generally include dosages of L-ornithine phenyl acetate in the range of about 500 mg to about 100 g (preferably about 1 g to about 50 g). In some embodiments, the intravenous formulation is substantially free of alkali metal salts and halides (e.g., contains no more than trace amounts of alkali metal salts and halides). In some embodiments, the intravenous formulation has a concentration of about 5 to about 300 mg/mL of L-ornithine phenyl acetate (preferably about 25 to about 200 mg/mL, and more preferably about 40 to about 60 mg/mL).

[0108] The composition, or medicament containing said composition, may optionally be placed in sealed packaging. The sealed packaging may reduce or prevent moisture and/or ambient air from contacting the composition or medicament. In some embodiments, the packaging includes a hermetic seal. In some embodiments, the packaging is sealed under vacuum or with an inert gas (e.g., argon) within the sealed package. Accordingly, the packaging can inhibit or reduce the rate of degradation for the composition or medicament stored within the packaging. Various types of sealed packaging are known in the art. For example, U.S. Patent Number 5,560,490, is hereby incorporated by reference in its entirety, discloses an exemplary sealed package for medicaments.

Compositions with Improved Density

[0109] Applicants have surprisingly found that compositions with greater density may be obtained by applying sufficient pressure to compositions having Form I (described below) to induce a transition to Form II (described below). For example, applying 3 tons of force for 90 minutes to Forms I and II yield densities of 1.197 kg/m³ and 1.001 kg/m³, respectively. Surprisingly, Form I converted to Form II under these conditions; therefore the greater density appears to be explained by the different crystalline form as the starting material.

[0110] Accordingly, disclosed herein are methods of increasing the density of an L-ornithine phenyl acetate composition having Form I by applying pressure to the composition sufficient to induce a transition to Form II. The appropriate amount of force or pressure to induce the phase change may vary with the amount of time the force or pressure is applied. Thus, a person of ordinary skill, guided by the teachings of the present application, can determine appropriate amounts of pressure and time to induce the phase change. In some embodiments, at least about 1 ton of force is applied (preferably at least about 2 tons, and more preferably about 3 tons). In some embodiments, at least about 500 psi of pressure is applied (preferably at least about 1000 psi, and more preferably at least about 2000 psi).

[0111] The amount of time for applying pressure is not particularly limited, and as discussed above, will vary depending upon the amount of time. For example, when applying large forces (e.g., 10 tons) to a typical tablet-sized punch, the time may be about 1 second or less. In some embodiments, the time for applying pressure is a predetermined

time. The time may be, for example, about 0.1 seconds; about 1 second; at least about 1 minute; at least about 5 minutes; or at least about 20 minutes.

[0112] In some embodiments, the composition includes at least about 10% by weight of Form I. In some embodiments, the composition includes at least about 30% by weight of Form I.

[0113] Without being bound to any particular theory, Applicants believe the greater density may result, at least in part, from ethanol solvate component present in Form I. Applying pressure to the solvate may facilitate forming a denser structure with fewer defects (e.g., grain boundaries). Consequently, in some embodiments, methods of increasing the density of an L-ornithine phenyl acetate composition having solvate components include applying pressure to the composition sufficient to induce a transition to Form II. In some embodiments, the pressure is at least about 500 psi (preferably at least about 1000 psi, and more preferably at least about 2000 psi). In some embodiments, the time for apply pressure is a predetermined time. In some embodiments, the composition includes at least about 10% of the solvate form (preferably at least about 30%, and more preferably at least about 50%).

[0114] The compositions of L-ornithine phenyl acetate disclosed herein may therefore have higher densities compared to compositions obtain by, for example, precipitating a crystalline form. In some embodiments, the composition has a density of at least about 1.1 kg/m³ (preferably at least about 1.15 kg/m³, and more preferably at least about 1.18 kg/m³). In some embodiments, the composition has a density of no more than about 1.3 kg/m³ (preferably no more than about 1.25 kg/m³, and more preferably no more than about 1.22 kg/m³). In some embodiments, the composition has a density of about 1.2 kg/m³.

Crystalline Forms of L-Ornithine Phenyl Acetate

[0115] Also disclosed herein are crystalline forms of L-ornithine phenyl acetate, and in particular, crystalline Form I, Form II, Form III, and Form V. L-Ornithine phenyl acetate may, in some embodiments, be obtained using the processes disclosed above and then crystallized using any of the methods disclosed herein.

Form I

[0116] The precise conditions for forming crystalline Form I may be empirically determined and it is only possible to give a number of methods which have been found to be suitable in practice.

[0117] Thus, for example, crystalline Form I may generally be obtained by crystallizing L-ornithine phenyl acetate under controlled conditions. As an example, precipitating L-ornithine phenyl acetate from a saturated solution by adding ethanol at reduced temperatures (e.g., 4° or -21° C). Exemplary solvents for the solution that yield crystalline Form I upon adding ethanol include, but are not limited to, cyclohexanone, 1-propanol, diethylcarbonate, N-methylpyrrolidine (NMP), diethyl ether, 2-butanol, cumene, ethyl formate, isobutyl acetate, 3-nethyl-1-butanol, and anisole.

[0118] Accordingly, in the context of the processes for making L-ornithine phenyl acetate disclosed above, the process can yield Form I by utilizing particular isolation methods. For example, L-ornithine phenyl acetate may be isolated by adding ethanol at reduced temperature to yield Form I.

[0119] Crystalline Form I was characterized using various techniques which are described in further detail in the experimental methods section. FIGURE 1 shows the crystalline structure of Form I as determined by X-ray powder diffraction (XRPD). Form I, which may be obtained by the methods disclosed above, exhibits characteristic peaks at approximately 4.9°, 13.2°, 17.4°, 20.8° and 24.4° 2 θ . Thus, in some embodiments, a crystalline form of L-ornithine phenyl acetate has one or more characteristic peaks (e.g., one, two, three, four or five characteristic peaks) selected from approximately 4.9°, 13.2°, 17.4°, 20.8°, and 24.4° 2 θ .

[0120] As is well understood in the art, because of the experimental variability when X-ray diffraction patterns are measured on different instruments, the peak positions are assumed to be equal if the two theta (2 θ) values agree to within 0.2° (i.e., $\pm 0.2^\circ$). For example, the United States Pharmacopeia states that if the angular setting of the 10 strongest diffraction peaks agree to within $\pm 0.2^\circ$ with that of a reference material, and the relative intensities of the peaks do not vary by more than 20%, the identity is confirmed. Accordingly, peak positions within 0.2° of the positions recited herein are assumed to be identical.

[0121] FIGURE 2 shows results obtained by differential scanning calorimetry (DSC) for Form I. These results indicate an endotherm at 35° C, which is possibly

associated with a desolvation and/or dehydration to Form II. A second transition at about 203° C indicates the melting point for the crystal. To explore the possible existence of a desolvation and/or dehydration transition, Form I was analyzed by thermogravimetric gravimetric/differential thermal analysis (TG/DTA), which is shown in FIGURE 3. Form I exhibits a 11.28% weight loss at about 35° C, and therefore these results further suggest that Form I exhibits a desolvation and/or dehydration transition at about 35° C. The melting point of about 203° C could also be observed by TGA testing. Accordingly, in some embodiments, the crystalline form of L-ornithine phenyl acetate is characterized by differential scanning calorimetry as having an endotherm at about 35° C. In some embodiments, a crystalline form of L-ornithine phenyl acetate exhibits a weight loss of about 11% at about 35° C, as determined by TGA. In some embodiments, a crystalline form of L-ornithine phenyl acetate exhibits a melting point of about 203° C.

[0122] FIGURE 4 shows nuclear magnetic resonance (NMR) integrals and chemical shifts for Form I. The integrals confirm the presence of L-ornithine phenyl acetate: 7.5 (aromatic CH), 3.8 (CH adjacent to NH₂), 3.6 (CH₂ unit of phenyl acetate), 3.15 (CH₂ adjacent to NH₂) and 1.9 (aliphatic CH₂ units) ppm (integrals: 5:1:2:2:4 protons; 1.2, 0.25, 0.5, 0.5, 1.0). Amine protons and hydroxyl protons were not observed due to proton exchange at both the zwitterion and site of salt formation. Meanwhile, FIGURE 5 shows dynamic vapor sorption (DVS) results for Form I, and show a water uptake of about 0.2% by weight. XRPD results following DVA analysis (not shown) confirm that Form I did not transition to a different polymorph. Form I can therefore be characterized as non-hygroscopic and stable over a wide range of humidity.

[0123] A 7-day stability study of Form I at 40°C/75%RH indicated that a transformation to Form II occurred under these conditions. Form I also converts to Form II at elevated temperatures (*e.g.*, 80° or 120° C), with or without applying a vacuum, after 7 or 14 days. Accordingly, Form I is metastable.

[0124] Single crystal x-ray diffraction (SXRD) was also used to determine the structure of Form I at -20° and -123° C, and the results are summarized in TABLES 1 and 2. The results confirm that Form I is a solvate having ethanol and water molecules within the unit cell. In some embodiments, a crystalline form of L-ornithine phenyl acetate can be represented by the formula C₁₅H₂₈N₂O₆. In some embodiments, a crystalline form of L-ornithine phenyl acetate can be represented by the formula [C₅H₁₃N₂O₂][C₈H₇O₂]EtOH.H₂O. In some embodiments, a crystalline form of L-

ornithine phenyl acetate exhibits a single crystal X-ray crystallographic analysis with crystal parameters approximately equal to the following: unit cell dimensions of $a=5.3652(4)$ Å, $b=7.7136(6)$ Å, $c=20.9602(18)$ Å, $\alpha=90^\circ$, $\beta=94.986(6)^\circ$, $\gamma=90^\circ$; a monoclinic crystal system, and a $P2_1$ space group.

TABLE 1 – Crystallographic Data of Form I Collected at -20° C

Empirical Formula	$C_{15}H_{28}N_2O_6$ or [C ₅ H ₁₃ N ₂ O ₂][C ₈ H ₇ O ₂].EtOH.H ₂ O
Formula Weight	332.39
Crystal System	Monoclinic
Space Group	$P2_1$
Unit Cell Dimensions	$a = 5.3652(4)$ Å $\alpha = 90^\circ$ $b = 7.7136(6)$ Å $\beta = 94.986(6)^\circ$ $c = 20.9602(18)$ Å $\gamma = 90^\circ$
Volume	$864.16(12)$ Å ³
Number of Reflections	1516 ($2.5^\circ < \theta < 28^\circ$)
Density (calculated)	1.277 mg/cm ³

TABLE 2 – Crystallographic Data of Form I Collected at -123° C

Empirical Formula	$C_{15}H_{28}N_2O_6$ or [C ₅ H ₁₃ N ₂ O ₂][C ₈ H ₇ O ₂].EtOH.H ₂ O
Formula Weight	332.39
Crystal System	Monoclinic
Space Group	$P2_1$
Unit Cell Dimensions	$a = 5.3840(9)$ Å $\alpha = 90^\circ$ $b = 7.7460(12)$ Å $\beta = 95.050(12)^\circ$ $c = 21.104(4)$ Å $\gamma = 90^\circ$
Volume	$876.7(3)$ Å ³
Number of Reflections	1477 ($2.5^\circ < \theta < 18^\circ$)
Density (calculated)	1.259 mg/cm ³

Form II

[0125] The precise conditions for forming crystalline Form II may be empirically determined and it is only possible to give a number of methods which have been found to be suitable in practice.

[0126] Thus, for example, crystalline Form II may be prepared by crystallization under controlled conditions. Crystalline Form II can be prepared by, for example, evaporating a saturated organic solution of L-ornithine phenyl acetate. Non-limiting examples of organic solutions that may be used to obtain Form II include ethanol, acetone, benzonitrile, dichloromethane (DCM), dimethyl sulfoxide (DMSO), ethyl acetate (EtOAc), acetonitrile (MeCN), methyl acetate (MeOAc), nitromethane, tert-butyl methyl ether (TBME), tetrahydrofuran, and toluene. Other solvents may yield a mixture of Form I and II, such as, but not limited to, 1,4 dioxane, 1-butanol, cyclohexane, IPA, THF, MEK, MeOAc and water.

[0127] Form II can also be obtained by precipitating L-ornithine phenyl acetate from a saturated organic solution by adding an anti-solvent for L-ornithine phenyl acetate, such as IPA. Form II may be precipitated over a broad range of temperatures (*e.g.*, room temperature, 4° C, and -21° C). Non-limiting examples of suitable solvents for the saturated organic solution include cyclohexanone, 1-propanol, dimethyl carbonate, N-methylpyrrolidone (NMP), diisopropyl ether, diethyl ether, ethylene glycol, dimethylformamide (DMF), 2-butanol, cumene, isobutyl acetate, 3-methyl-1-butanol, and anisole. Alternatively, the same listed solvents (*e.g.*, cyclohexanone) can be used to form a solution of L-ornithine phenyl acetate, and Form II may be precipitated by adding ethanol at ambient conditions. As another example, Form II may also be obtained by forming a slurry of L-ornithine phenyl acetate with the listed organic solvents and cycling the temperature between 25° and 40° C every 4 hours for about 18 cycles (or 72 hours).

[0128] Accordingly, in the context of the processes for making L-ornithine phenyl acetate disclosed above, the process can yield Form II by utilizing particular isolation methods. For example, L-ornithine phenyl acetate may be isolated by adding IPA, or evaporating the organic solvent, to yield Form II.

[0129] FIGURE 6 shows the crystalline structure of Form II as determined by XRPD. Form II, which may be obtained by the methods disclosed above, exhibits characteristic peaks at approximately 6.0°, 13.9°, 14.8°, 17.1°, 17.8° and 24.1° 2 θ . Thus, in some embodiments, a crystalline form of L-ornithine phenyl acetate has one or more

characteristic peaks (*e.g.*, one, two, three, four, five or six characteristic peaks) selected from approximately 6.0°, 13.9°, 14.8°, 17.1°, 17.8° and 24.12° θ .

[0130] FIGURE 7 shows results obtained by differential scanning calorimetry (DSC) for Form II. These results indicate a melting point of about 202° C, which is approximately the same as the melting point for Form I. This suggests that Form I transitions to Form II upon heating above about 35° C. Form II was also analyzed using TG/DTA, as shown in FIGURE 8, and exhibits an about 9.7% weight loss associated with residual solvent. The melting point of about 202° C could also be observed by TGA testing. Accordingly, in some embodiments, a crystalline form of L-ornithine phenyl acetate exhibits a melting point of about 202° C.

[0131] A 7-day stability study of Form II at 40°C/75%RH failed to produce an observable phase change. In fact, Form II was stable over 14 days when exposed to elevated temperatures, varying pHs, UV light or oxygen. Accordingly, Form II is considered stable.

[0132] FIGURE 9 shows nuclear magnetic resonance (NMR) integrals and chemical shifts for Form II. The integrals confirm the presence of L-ornithine phenyl acetate: 7.5 (aromatic CH), 3.8 (CH adjacent to NH₂), 3.6 (CH₂ unit of phenylacetate), 3.15 (CH₂ adjacent to NH₂) and 1.9 (aliphatic CH₂ units) ppm (integrals: 5:1:2:2:4 protons; 7.0, 1.4, 2.9, 3.0, 5.9). Amine protons and hydroxyl protons were not observed due to proton exchange at both the zwitterion and site of salt formation. Meanwhile, FIGURE 10 shows dynamic vapor sorption (DVS) results for Form II, and show a water uptake of about 0.3% by weight. XRPD results following DVA analysis (not shown) confirm that Form II did not transition to a different polymorph. Form II can therefore be characterized as non-hygroscopic and stable over a wide range of humidity.

[0133] Single crystal x-ray diffraction (SXRD) was also used to determine the structure of Form II at 23° and -123° C, and the results are summarized in TABLES 3 and 4. The results demonstrate that Form II is anhydrous and therefore structurally different from Form I. In some embodiments, a crystalline form of L-ornithine phenyl acetate can be represented by the formula C₁₃H₂₀N₂O₄. In some embodiments, a crystalline form of L-ornithine phenyl acetate can be represented by the formula [C₅H₁₃N₂O₂][C₈H₇O₂]. In some embodiments, a crystalline form of L-ornithine phenyl acetate exhibits a single crystal X-ray crystallographic analysis with crystal parameters approximately equal to the

following: unit cell dimensions of $a = 6.594(2) \text{ \AA}$, $\alpha = 90^\circ$, $b = 6.5448(18) \text{ \AA}$, $\beta = 91.12(3)^\circ$, $c = 31.632(8) \text{ \AA}$, $\gamma = 90^\circ$; a monoclinic crystal system; and a $P2_1$ space group.

TABLE 3 – Crystallographic Data of Form II Collected at 23° C

Empirical Formula	$C_{13}H_{20}N_2O_4$ or $[C_5H_{13}N_2O_2][C_8H_7O_2]$
Formula Weight	268.31
Crystal System	Monoclinic
Space Group	$P2_1$
Unit Cell Dimensions	$a = 6.594(2) \text{ \AA}$ $\alpha = 90^\circ$ $b = 6.5448(18) \text{ \AA}$ $\beta = 91.12(3)^\circ$ $c = 31.632(8) \text{ \AA}$ $\gamma = 90^\circ$
Volume	$1364.9(7) \text{ \AA}^3$
Number of Reflections	3890 ($3^\circ < \theta < 20.5^\circ$)
Density (calculated)	1.306 mg/cm^3

TABLE 4 – Crystallographic Data of Form II Collected at -123° C

Empirical Formula	$C_{15}H_{28}N_2O_6$ or $[C_5H_{13}N_2O_2][C_8H_7O_2]$
Formula Weight	332.39
Crystal System	Monoclinic
Space Group	$P2_1$
Unit Cell Dimensions	$a = 5.3652(4) \text{ \AA}$ $\alpha = 90^\circ$ $b = 7.7136(6) \text{ \AA}$ $\beta = 94.986(6)^\circ$ $c = 20.9602(18) \text{ \AA}$ $\gamma = 90^\circ$
Volume	$864.16(12) \text{ \AA}^3$
Number of Reflections	1516 ($2.5^\circ < \theta < 28^\circ$)
Density (calculated)	1.277 mg/cm^3

Form III

[0134] The precise conditions for forming crystalline Form III may be empirically determined and it is only possible to give a number of methods which have been found to be suitable in practice.

[0135] Thus, for example, Form III may be obtained by placing a saturated solution of L-ornithine phenyl acetate in a cooled temperature environment of about -21°C , where the solution is a mixture of acetone and water (e.g., equal parts volume of acetone and water). As another example, adding IPA to a saturated solution of L-

ornithine phenyl acetate in 2-butanol can yield Form III when completed at ambient conditions. Furthermore, Form III may be obtained, for example, by adding IPA to a saturated solution of L-ornithine phenyl acetate in isobutyl acetate when completed at reduced temperatures of about -21° C.

[0136] Accordingly, in the context of the processes for making L-ornithine phenyl acetate disclosed above, the process can yield Form III by utilizing particular solvents and isolation methods. For example, L-ornithine phenyl acetate may be formed within a mixture of acetone and water, and subsequently placed in a cool environment of about -21° C to yield Form III.

[0137] FIGURE 11 shows the crystalline structure of Form III as determined by XRPD. Form III, which may be obtained by the methods disclosed above, exhibits characteristic peaks at approximately 5.8°, 14.1°, 18.6°, 19.4°, 22.3° and 24.8° 2 θ . Thus, in some embodiments, a crystalline form of L-ornithine phenyl acetate has one or more characteristic peaks (e.g., one, two, three, four, five or six characteristic peaks) selected from approximately 5.8°, 14.1°, 18.6°, 19.4°, 22.3° and 24.8° 2 θ .

[0138] FIGURE 12 shows results obtained by differential scanning calorimetry (DSC) for Form III. These results indicate a melting point of about 203° C, which is approximately the same as the melting points for Form I and Form II. Additionally, Form III exhibits an endotherm at about 40° C. Form III was also analyzed using TG/DTA, as shown in FIGURE 13, and exhibits no significant weight loss before the melting point. Form III may therefore be characterized as anhydrous. The melting point of about 203° C could also be observed by TGA testing. Accordingly, in some embodiments, a crystalline form of L-ornithine phenyl acetate exhibits a melting point of about 203° C. In some embodiments, a crystalline form of L-ornithine phenyl acetate is characterized by differential scanning calorimetry as having an endotherm at about 40° C. In some embodiments, a crystalline form of L-ornithine phenyl acetate is anhydrous.

[0139] A 7-day stability study of Form III at 40°C/75%RH indicated that a transformation to Form II occurred under these conditions. In contrast, Form II is stable at elevated temperatures, with or without vacuum, for periods of 7 or 10 days. Accordingly, Form III is most likely metastable, but more stable than Form I.

[0140] FIGURE 14 shows nuclear magnetic resonance (NMR) integrals and chemical shifts for Form III. The integrals confirm the presence of L-ornithine phenyl acetate: 7.5 (aromatic CH), 3.8 (CH adjacent to NH₂), 3.6 (CH₂ unit of phenyl acetate),

3.15 (CH₂ adjacent to NH₂) and 1.9 (aliphatic CH₂ units) ppm (integrals: 5:1:2:2:4 protons; 4.2, 0.8, 1.7, 1.7, 3.0). Amine protons and hydroxyl protons were not observed due to proton exchange at both the zwitterion and site of salt formation. Meanwhile, FIGURE 15 shows dynamic vapor sorption (DVS) results for Form III, and show a water uptake of about 2.0% by weight. XRPD results following DVS analysis (not shown) confirm that Form III did not transition to a different polymorph. Form III therefore exhibits greater water uptake compared to Forms I and II; however Form III is still characterized as non-hygroscopic and stable over a wide range of humidity at room temperature.

Form V

[0141] The precise conditions for forming crystalline Form V may be empirically determined and it is only possible to give a number of methods which have been found to be suitable in practice.

[0142] Thus, for example, Form V may be obtained by placing a saturated solution of L-ornithine phenyl acetate in a cooled temperature environment of about -21° C, where the solution is cyclohexanone. As another example, the same saturated solution may yield Form V when evaporating the solvent.

[0143] Form V also forms from saturated solutions of L-ornithine phenyl acetate having diisopropyl ether as a solvent. For example, a saturated solution having a solvent ratio of about 1 to 2 of diisopropyl ether and IPA will yield Form V when placed in a cooled temperature environment of about 4° C. Similarly, a solution having only the solvent diisopropyl ether can yield Form V when placed in a cooled temperature environment of about -21° C.

[0144] FIGURE 16 shows the crystalline structure of Form V as determined by XRPD. Form V, which may be obtained by the methods disclosed above, exhibits characteristic peaks at approximately 13.7°, 17.4°, 19.8°, 20.6° and 23.7° 2 θ . Thus, in some embodiments, a crystalline form of L-ornithine phenyl acetate has one or more characteristic peaks (e.g., one, two, three, four, or five characteristic peaks) selected from approximately 13.7°, 17.4°, 19.8°, 20.6° and 23.7° 2 θ .

[0145] FIGURE 17 shows results obtained by differential scanning calorimetry (DSC) for Form V. These results indicate a melting point of about 196° C, which is below the melting point of other forms. Form V also exhibits an endotherm at about 174° C. Form V was also analyzed using thermal gravimetric analysis (TGA), as

shown in FIGURE 18, and exhibits no significant weight loss before the melting point. Form V may therefore be characterized as anhydrous. The melting point of about 196° C could also be observed by TGA testing. Accordingly, in some embodiments, a crystalline form of L-ornithine phenyl acetate exhibits a melting point of about 196° C. In some embodiments, a crystalline form of L-ornithine phenyl acetate is characterized by differential scanning calorimetry as having an endotherm at about 174° C. In some embodiments, a crystalline form of L-ornithine phenyl acetate is anhydrous.

[0146] FIGURE 19 shows nuclear magnetic resonance (NMR) integrals and chemical shifts for Form V. The integrals confirm the presence of L-ornithine phenyl acetate: 7.5 (aromatic CH), 3.8 (CH adjacent to NH₂), 3.6 (CH₂ unit of phenyl acetate), 3.15 (CH₂ adjacent to NH₂) and 1.9 (aliphatic CH₂ units) ppm (integrals: 5:1:2:2:4 protons; 4.2, 0.8, 1.7, 1.7, 3.0). Amine protons and hydroxyl protons were not observed due to proton exchange at both the zwitterion and site of salt formation. Meanwhile, FIGURE 19 shows dynamic vapor sorption (DVS) results for Form V, and show a water uptake of about 0.75% by weight. XRPD results following DVS analysis (not shown) suggest that Form V transitioned to Form II, but the chemical composition was unchanged. Form V is therefore characterized as non-hygroscopic, but not stable over a wide range of humidity.

[0147] A 7-day stability study of Form V at 40°C/75%RH indicated that a transformation to Form II occurred under these conditions; however the chemical composition was unchanged. Accordingly, Form V is most likely metastable.

Methods of Treating Liver Decompensation or Hepatic Encephalopathy

[0148] L-Ornithine phenyl acetate, and accordingly any of the compositions of L-ornithine phenyl acetate disclosed herein, may be administered to a subject for treating or ameliorating the onset of liver decompensation or hepatic encephalopathy. L-Ornithine phenyl acetate can thus be administered to improve the condition of a subject, for example a subject suffering from chronic liver disease following a precipitating event. As another example, L-ornithine phenyl acetate may be administered to combat or delay the onset of liver decompensation or hepatic encephalopathy.

[0149] L-Ornithine phenyl acetate may be administered in combination to a subject for treatment of hepatic encephalopathy. L-Ornithine phenyl acetate may be administered to improve the condition of a patient suffering from hepatic encephalopathy. L-Ornithine phenyl acetate may be administered to alleviate the symptoms associated with

hepatic encephalopathy. L-Ornithine phenyl acetate may be administered to combat hepatic encephalopathy. L-Ornithine phenyl acetate may be administered to prevent or reduce the likelihood of an initial hepatic encephalopathic episode in a person at risk for hepatic encephalopathic episodes. L-Ornithine phenyl acetate may be administered to lessen the severity of an initial hepatic encephalopathic episode in a person at risk for hepatic encephalopathic episodes. L-Ornithine phenyl acetate may be administered to delay an initial hepatic encephalopathic episode in a person at risk for hepatic encephalopathic episodes.

[0150] Development of liver decompensation and hepatic encephalopathy commonly involves "precipitating events" (or "acute attacks"). Such precipitating events include gastrointestinal bleeding, infection (sepsis), portal vein thrombosis and dehydration. The onset of such an acute attack is likely to lead to hospitalization. The patient may suffer one of these acute attacks or a combination of these acute attacks.

[0151] A subject who has had or is suspected of having had an acute attack is treated according to the invention with L-ornithine phenyl acetate to prevent or reduce the likelihood of progression of the liver to the decompensated state. Consequently, L-ornithine phenyl acetate can prevent or reduce the likelihood of the medical consequences of liver decompensation such as hepatic encephalopathy. L-Ornithine phenyl acetate may be used to preserve liver function. Use of L-ornithine phenyl acetate may thus extend the life of a patient with liver disease. In one embodiment, the metabolic consequences of a gastrointestinal bleed such as hyperammonemia, hypoisoleucemia and reduced protein synthesis in the post-bleeding period are prevented.

[0152] Typically, treatment of subjects may begin as soon as possible after the onset or the suspected onset of a precipitating event (acute attack). Preferably, treatment of the subject begins prior to repeated acute attacks. More preferably, treatment of the subject begins following the first acute attack. Thus, in some embodiments, the subject treated with L-ornithine phenyl acetate is identified as having the onset or the suspected onset of a precipitating event (acute attack).

[0153] Treatment is typically given promptly after the start of an acute attack. Treatment may begin after the symptom(s) of an acute attack or suspected acute attack have been detected e.g. by a medic such as a physician, a paramedic or a nurse. Treatment may begin upon hospitalization of the subject. Treatment may thus begin within 6 hours, within 3 hours, within 2 hours or within 1 hour after the symptom(s) of an acute attack or

suspected acute attack have been detected. Treatment of the subject may therefore begin from 1 to 48 hours, for example from 1 to 36 hours or from 1 to 24 hours after the symptom(s) of an acute attack or suspected acute attack have been detected.

[0154] Treatment may occur for up to 8 weeks, for example up to 6 weeks, up to 4 weeks or up to 2 weeks after the symptom(s) of an acute attack or suspected acute attack have been detected. Treatment may therefore occur for up to 48 hours, for example for up to 36 hours or for up to 24 hours after the symptom(s) of an acute attack or suspected acute attack have been detected. Typically, treatment occurs to the time when recovery from the acute precipitating event is evident.

[0155] L-Ornithine phenyl acetate may also be used to treat or ameliorate hyperammonemia. Thus, L-ornithine phenyl acetate may be administered to patients identified as having excess ammonia levels in the blood, or patients exhibiting symptoms of excess ammonia in the blood. L-Ornithine phenyl acetate may also be administered to reduce the risk of hyperammonemia. In some embodiments, L-ornithine phenyl acetate can be administered daily, for an indefinite period of time. For example, daily dosages may be administered for the life of the patient, or until a physician determines the patient no longer exhibits a risk for hyperammonemia. In some embodiments, a therapeutically effective amount of L-ornithine phenyl acetate is administered to reduce the risk of hyperammonemia. In some embodiments, a therapeutically effective amount of L-ornithine phenyl acetate is administered orally for the prophylaxis of hyperammonemia.

[0156] A therapeutically effective amount of L-ornithine phenyl acetate is administered to the subject. As will be readily apparent to one skilled in the art, the useful *in vivo* dosage to be administered and the particular mode of administration will vary depending upon the age, weight, the severity of the affliction, and mammalian species treated, the particular compounds employed, and the specific use for which these compounds are employed. (See *e.g.*, Fingl *et al.* 1975, in "The Pharmacological Basis of Therapeutics", which is hereby incorporated herein by reference in its entirety, with particular reference to Ch. 1, p. 1). The determination of effective dosage levels, that is the dosage levels necessary to achieve the desired result, can be accomplished by one skilled in the art using routine pharmacological methods. Typically, human clinical applications of products are commenced at lower dosage levels, with dosage level being increased until the desired effect is achieved. Alternatively, acceptable *in vitro* studies

can be used to establish useful doses and routes of administration of the compositions identified by the present methods using established pharmacological methods.

[0157] A typical dose of L-ornithine phenyl acetate may be from about 0.02 to about 1.25 g/kg of bodyweight (preferably from about 0.1 to about 0.6 g/kg of bodyweight). A dosage may therefore be from about 500 mg to about 50 g (preferably about 5 g to about 40 g, and more preferably about 10 g to about 30 g).

[0158] A single daily dose may be administered. Alternatively, multiple doses, for example two, three, four or five doses may be administered. Such multiple doses may be administered over a period of one month or two weeks or one week. In some embodiments, a single dose or multiple doses such as two, three, four or five doses may be administered daily.

EXAMPLES AND EXPERIMENTAL METHODS

[0159] Additional embodiments are disclosed in further detail in the following examples, which are not in any way intended to limit the scope of the claims.

X-ray Powder Diffraction (XRPD)

[0160] XRPD analysis was carried out on a Bruker D8 advance or Seimens D5000, scanning the samples between 4° and 50° 2 θ . In embodiments using the Bruker D8 device, approximately 5 mg of a sample was gently compressed on the XRPD zero back ground single 96 well plate sample holder. The sample was then loaded into a Bruker D8-Discover diffractometer in transmission mode and analysed using the following experimental conditions.

[0161]	Operator	D8-Discover
[0162]	Raw Data Origin	BRUKER-binary V3 (.RAW)
[0163]	Scan Axis	Gonio
[0164]	Start Position [°2 θ .]	4.0000
[0165]	End Position [°2 θ .]	49.9800
[0166]	Step Size [°2 θ .]	0.0200
[0167]	Scan Step Time [s]	39.1393
[0168]	Scan Type	Continuous
[0169]	Offset [°2 θ .]	0.0000
[0170]	Divergence Slit Type	Fixed
[0171]	Divergence Slit Size [°]	2.0000

[0172]	Specimen Length [mm]	10.00
[0173]	Receiving Slit Size [mm]	0.1000
[0174]	Measurement Temperature [°C]	25.00
[0175]	Anode Material	Cu
[0176]	K-Alpha1 [Å]	1.54060
[0177]	K-Alpha2 [Å]	1.54443
[0178]	K-Beta [Å]	1.39225
[0179]	K-A2 / K-A1 Ratio	0.50000
[0180]	Generator Settings	40 mA, 40 kV
[0181]	Diffraction Type	Unknown
[0182]	Diffraction Number	0
[0183]	Goniometer Radius [mm]	250.00
[0184]	Dist. Focus-Diverg. Slit [mm]	91.00
[0185]	Incident Beam Monochromator	No
[0186]	Spinning	No

[0187] In embodiments using the Seimens D5000 device, approximately 5 mg of sample was gently compressed on glass slide containing a thin layer of holding grease. The sample was then loaded into a Seimens D5000 diffractometer running in reflection mode and analysed, whilst spinning, using the following experimental conditions.

[0188]	Raw Data Origin	Siemens-binary V2 (.RAW)
[0189]	Start Position [°2 θ .]	3.0000
[0190]	End Position [°2 θ .]	50.000
[0191]	Step Size [°2 θ .]	0.0200
[0192]	Scan Step Time [s]	0.8
[0193]	Scan Type	Continuous
[0194]	Offset [°2 θ .]	0.0000
[0195]	Divergence Slit Type	Fixed
[0196]	Divergence Slit Size [°]	1.0000
[0197]	Specimen Length [mm]	various
[0198]	Receiving Slit Size [mm]	0.2000
[0199]	Measurement Temperature [°C]	20.00

[0200]	Anode Material	Cu
[0201]	K-Alpha1 [Å]	1.54060
[0202]	K-Alpha2 [Å]	1.54443
[0203]	K-Beta [Å]	1.39225
[0204]	K-A2 / K-A1 Ratio	0.50000 (nominal)
[0205]	Generator Settings	40 mA, 40 kV
[0206]	Diffractometer Type	d5000
[0207]	Diffractometer Number	0
[0208]	Goniometer Radius [mm]	217.50
[0209]	Incident Beam Monochromator	No
[0210]	Diffacted Beam Monochromator	(Graphite)
[0211]	Spinning	Yes

Single Crystal X-ray Diffraction (SXRD)

[0212] All measurements were carried out using a Bruker Smart Apex diffractometer operating with Mo-K α radiation. Unless otherwise specified the data were obtained in 60 ω -scan 10 s images collected in three separate settings of 2θ and ϕ .

Differential Scanning Calorimetry (DSC)

[0213] Approximately 5 mg of sample was weighed into an aluminium DSC pan and sealed with a pierced aluminium lid (non-hermetically). The sample pan was then loaded into a Seiko DSC6200 (equipped with a cooler), cooled, and held at 25 °C. Once a stable heat-flow response was obtained, the sample and reference were then heated to about 250 °C at a scan rate of 10 °C/min and the resulting heat flow response monitored. Prior to analysis, the instrument was temperature and heat-flow calibrated using an indium reference standard. Sample analysis was carried out by Muse measurement software where the temperatures of thermal events were quoted as the onset temperature, measured according to the manufacturer's specifications.

Thermogravimetric Gravimetric/Differential Thermal Analysis (TG/DTA)

[0214] Approximately 5 mg of sample was weighed into an aluminium pan and loaded into a simultaneous thermogravimetric/differential thermal analyser (DTA) and held at room temperature. The sample was then heated at a rate of 10 °C/min from 25 °C to 300 °C during which time the change in sample weight was monitored along with any thermal events (DTA). Nitrogen was used as the purge gas, at a flow rate of 20

cm³/min. Prior to analysis the instrument was weight and temperature calibrated using a 100 mg reference weight and an indium reference standard, respectively.

Dynamic Vapor Sorption (DVS)

[0215] Approximately 10 mg of sample was placed into a wire-mesh vapor sorption balance pan and loaded into a DVS-1 dynamic vapor sorption balance supplied by Scientific and Medical Systems (SMS). The sample was then dried by maintaining a 0% humidity environment until no further weight change was recorded. The sample was then subjected to a ramping profile from 0 – 90% relative humidity (RH) at 10% increments, maintaining the sample at each step until a stable weight had been achieved (99.5% step completion). After completion of the sorption cycle, the sample was then dried using the same procedure. The weight change during the sorption/desorption cycles were then plotted, allowing for the hygroscopic nature of the sample to be determined.

¹H Nuclear Magnetic Resonance (NMR)

[0216] ¹H NMR was performed on a Bruker AC200. An NMR of each sample was performed in d-H₂O and each sample was prepared to about 5 mg concentration. The NMR spectra for L-ornithine benzoate and L-ornithine phenyl acetate are provided in FIGURES 21 and 22, respectively.

Solubility Approximations

[0217] Approximately, 25 mg portions of the sample were placed in vials 5 volume increments of the appropriate solvent system were added. Between each addition, the mixture was checked for dissolution and if no dissolution was apparent, the mixture was warmed to 50°C, and checked again. The procedure was continued until dissolution was observed or when 100 volumes of solvent had been added.

HPLC Solubility Determinations

[0218] Slurries of each solvent were prepared and the samples shaken for about 48 hrs at 25°C. Each sample was then drawn through a filter, and the filtrate transferred to an HPLC vial for analysis. From the data the solubility of L-ornithine phenyl acetate for each solvent was determined.

Temperature Cycling Experiments

[0219] Using the information gathered from the solubility approximations, slurries of the sample were prepared in 24 selected solvent systems. The slurries were temperature cycled at 40°C or 25°C in 4 hour cycles for a period of 72 hours. The solids were visually checked for any obvious signs of degradation (i.e. color changes) and then,

if not degraded, isolated by filtration. The solids were allowed to dry at ambient conditions for about 24 hours prior to analysis.

Crash Cooling Experiments

[0220] Crash cooling experiments were performed by placing saturated solutions of the sample, in the 24 selected solvent systems, in environments of 4°C and -21°C for about 48 hours. Any solid material was recovered and the solids were allowed to dry at ambient conditions for about 24 hours prior to analysis.

Evaporation Experiments

[0221] Evaporation experiments were conducted by allowing saturated solutions of the sample to evaporate freely at ambient conditions. The solid material was then recovered after the material had evaporated to dryness and analyzed.

Anti-solvent Addition Experiments

[0222] Anti-solvent addition experiments were conducted by adding anti-solvent to saturated solutions of the sample. The addition was continued until there was no further precipitation and the samples adjusted to various temperature for 24 hours: elevated, ambient, 4° C or -21°. The solid was then isolated and dried at ambient conditions for about 24 hours prior to analysis.

Polarized Light Microscopy (PLM)

[0223] The presence of crystallinity (birefringence) was determined using a Leica Leitz DMRB polarised optical microscope equipped with a high resolution Leica camera and image capture software (Firecam V.1.0). All images were recorded using a 10x objective, unless otherwise stated.

Silver Analysis

[0224] All silver analysis was carried out on an Agilent 7500ce ICP-MS.

Intrinsic Dissolution Rates

[0225] Approximately 100 mg of each form was compressed into discs by placing the material into a die (diameter 12 mm) and compressing the die under 5 tons of pressure in a hydraulic press for about 2 minutes. The dissolution instrument, Sotax AT7 conforms to EP2 and USP2 in which paddles were used to stir the media. Each form was tested under the following pH conditions; 1.0, 4.5 and 6.7, in the stationary disc mode (i.e. discs were added at time=0 seconds and allowed to sink to the bottom of the media). 1 cm³ aliquots of media were extracted from the dissolution pots at times 10, 20, 30, 40, 50, 60, 70, 80 and 120 seconds and tested for API concentration by HPLC. Dissolution

curves were plotted and from the first 6 or 7 points on the curves the intrinsic dissolution rate curves were calculated. All tests were carried out at 37° C and a paddle speed of 150 rpm.

HPLC-UV Instrument Details

Instrument:	Agilent 1200
Column:	Gemini C18, 5µm, 150.0 x 4.6mm
Column Temperature:	40°C
Mobile Phase A:	Phosphate Buffer
Mobile Phase B:	Acetonitrile
Elution:	Gradient
λ:	210nm
Injection Volume:	10µL
Flow Rate:	1 mL/min

Thin Layer Chromatography (TLC)

[0226] A small spot of solution containing the sample was applied to a plate, about one centimeter from the base. The plate is then dipped into the TLC tank (sealed container) containing methanol:ethyl acetate (95:5) solvent mixture. The solvent moves up the plate by capillary action and meets the sample mixture, which is dissolved and is carried up the plate by the solvent mixture. The number of spots was noted and the R_f values were calculated for each spot.

Infrared (IR)

[0227] Infrared spectroscopy was carried out on a Bruker ALPHA P spectrometer. Sufficient material was placed onto the centre of the plate of the spectrometer and the spectra were obtained using the following parameters:

[0228]	Resolution:	4 cm ⁻¹
[0229]	Background Scan Time:	16 scans
[0230]	Sample Scan Time:	16 scans
[0231]	Data Collection:	4000 to 400 cm ⁻¹
[0232]	Result Spectrum:	Transmittance
[0233]	Software:	OPUS version 6

Stabilities Studies: pH 1, 4, 7, 10 and 14 Environments

[0234] Slurries (supersaturated solution: about 250 µl of pH solution and solid was added until dissolution was no longer observed and ca. 100 mg of solid was in the slurry) were prepared for each form in a variety of pH environments; 1, 4, 7, 10 and 13.2.

The slurries were shaken constantly for a period of 14 days and measurements taken at 7 and 14 day time points. Appropriate buffers were prepared for each pH and are detailed further below.

[0235] A buffer having a pH value of 1 was prepared by dissolving 372.75 mg of potassium chloride in 25 ml of deionized water to give a 0.2 M solution. Subsequently, 67 ml of 0.2 M hydrochloric acid was added (this was prepared from a 5 M solution; 10 ml was added to 40 ml of deionized water giving a 1 M solution which was diluted further; 20 ml was added to 80 ml of deionized water giving the required 0.2 M solution) to achieve the desired pH.

[0236] A buffer having a pH value of 4 was prepared by dissolving 1.02 g of potassium hydrogen phthalate in 50 ml of deionized water to give a 0.1 M solution.

[0237] A buffer having a pH value of 7 was prepared by dissolving 680.00 mg of potassium phosphate monobasic in 50 ml of deionized water to give a 0.1 M solution. Subsequently, 29.1 ml of 0.1 M sodium hydroxide was added (this was prepared from a 1 M solution; 5 ml was added to 45 ml of deionized water giving the required 0.1 M solution) to achieve the desired pH.

[0238] A buffer having a pH value of 10 was prepared by dissolving 210.00 mg of sodium bicarbonate in 50 ml of deionized water to give a 0.05 M solution. Subsequently, 10.7 ml of 0.1 M sodium hydroxide was added (this was prepared from a 1 M solution; 5 ml was added to 45 ml of deionized water giving the required 0.1 M solution) to achieve the desired pH.

[0239] A buffer having a pH value of pH 13.2 by dissolving 372.75 mg of potassium chloride in 25 ml of deionized water to give a 0.2 M solution. Subsequently, 66 ml of 0.2 M sodium hydroxide was added (this was prepared from a 1 M solution; 20 ml was added to 80 ml of deionized water giving the required 0.2 M solution) taking the pH to 13. 1M sodium hydroxide was then added drop wise to achieve the desired pH.

Example 1: Precipitating Crystalline Forms

[0240] Saturated solutions of L-ornithine phenyl acetate were subjected to temperature cycling, crash cooling, evaporation, or anti-solvent addition as described above. The precipitate was analyzed by PLM and XRPD to determine the crystalline form (if any). The results are summarized in TABLE 5.

[0241] Six unique crystalline forms were identified from the precipitation studies, Forms I-VI. However, Forms IV and VI were obtained from solutions of acetic acid, and NMR results confirmed these forms to be L-ornithine acetate. Meanwhile, Tests 540-611 utilized samples of L-ornithine phenyl acetate originally isolated by the addition of ethanol anti-solvent. Many of these example produced Form I, which is an ethanol solvate, and therefore it is believed these samples originally included residual ethanol. Consequently, Form I may not be reproduced for certain conditions if the original sample does not include residual ethanol.

TABLE 5 – Examples of Preparing Crystalline Forms

Test	Crystallization Method	Solvent	Results
1	Temp. Cycling	cyclohexanone	Form II
2	Controlled Cool (4°C)	cyclohexanone	No Solid
3	Controlled Cool (-21°C)	cyclohexanone	Form V
4	Evaporation	cyclohexanone	Form V
5	Anti-Solvent (IPA) Addition Elevated Temperature	cyclohexanone	No Solid
6	Anti-Solvent (IPA) Addition Ambient Temperature	cyclohexanone	Form II
7	Anti-Solvent (IPA) Addition (4°C)	cyclohexanone	Form II
8	Anti-Solvent (IPA) Addition (-21°C)	cyclohexanone	Form II
9	Anti-Solvent (Ethanol) Addition Ambient Temperature	cyclohexanone	Form II
10	Anti-Solvent (Ethanol) Addition (4°C)	cyclohexanone	Form I
11	Anti-Solvent (Ethanol) Addition (-21°C)	cyclohexanone	Form I
12	Temp. Cycling	ethanol/acetone (50:50)	Form II
13	Controlled Cool (4°C)	ethanol/acetone (50:50)	No Solid
14	Controlled Cool (-21°C)	ethanol/acetone (50:50)	Form III
15	Evaporation	ethanol/acetone (50:50)	Form II
16	Anti-Solvent (IPA) Addition Elevated Temperature	ethanol/acetone (50:50)	Form II
17	Anti-Solvent (IPA) Addition Ambient Temperature	ethanol/acetone (50:50)	Form II
18	Anti-Solvent (IPA) Addition (4°C)	ethanol/acetone (50:50)	Form II
19	Anti-Solvent (IPA) Addition (-21°C)	ethanol/acetone (50:50)	Form II
20	Anti-Solvent (Ethanol) Addition Ambient	ethanol/acetone (50:50)	Form II

Test	Crystallization Method	Solvent	Results
	Temperature		
21	Anti-Solvent (Ethanol) Addition (4°C)	ethanol/acetone (50:50)	Form I
22	Anti-Solvent (Ethanol) Addition (-21°C)	ethanol/acetone (50:50)	Form I
23	Temp. Cycling	acetic acid	Form IV
24	Controlled Cool (4°C)	acetic acid	No Solid
25	Controlled Cool (-21°C)	acetic acid	No Solid
26	Evaporation	acetic acid	Form II
27	Anti-Solvent (IPA) Addition Elevated Temperature	acetic acid	Form VI
28	Anti-Solvent (IPA) Addition Ambient Temperature	acetic acid	Form IV
29	Anti-Solvent (IPA) Addition (4°C)	acetic acid	Form IV
30	Anti-Solvent (IPA) Addition (-21°C)	acetic acid	Form IV
31	Anti-Solvent (Ethanol) Addition Ambient Temperature	acetic acid	Form IV
32	Anti-Solvent (Ethanol) Addition (4°C)	acetic acid	Form IV
33	Anti-Solvent (Ethanol) Addition (-21°C)	acetic acid	Form IV
34	Temp. Cycling	1-propanol	Form II
35	Controlled Cool (4°C)	1-propanol	Form II
36	Controlled Cool (-21°C)	1-propanol	Form II
37	Evaporation	1-propanol	Form II
38	Anti-Solvent (IPA) Addition Elevated Temperature	1-propanol	Form II
39	Anti-Solvent (IPA) Addition Ambient Temperature	1-propanol	Form II
40	Anti-Solvent (IPA) Addition (4°C)	1-propanol	Form II
41	Anti-Solvent (IPA) Addition (-21°C)	1-propanol	Form II
42	Anti-Solvent (Ethanol) Addition Ambient Temperature	1-propanol	Form II
43	Anti-Solvent (Ethanol) Addition (4°C)	1-propanol	Form I / II
44	Anti-Solvent (Ethanol) Addition (-21°C)	1-propanol	Form I
45	Temp. Cycling	dimethylcarbonate	Form II
46	Controlled Cool (4°C)	dimethylcarbonate	No Solid
47	Controlled Cool (-21°C)	dimethylcarbonate	Form II
48	Evaporation	dimethylcarbonate	Form II
49	Anti-Solvent (IPA) Addition Elevated Temperature	dimethylcarbonate	Form II
50	Anti-Solvent (IPA) Addition Ambient Temperature	dimethylcarbonate	Form II

Test	Crystallization Method	Solvent	Results
51	Anti-Solvent (IPA) Addition (4°C)	dimethylcarbonate	Form II
52	Anti-Solvent (IPA) Addition (-21°C)	dimethylcarbonate	Form II
53	Anti-Solvent (Ethanol) Addition Ambient Temperature	dimethylcarbonate	Form II
54	Anti-Solvent (Ethanol) Addition (4°C)	dimethylcarbonate	Form I
55	Anti-Solvent (Ethanol) Addition (-21°C)	dimethylcarbonate	Form II
56	Temp. Cycling	NMP	Form II
57	Controlled Cool (4°C)	NMP	Form II
58	Controlled Cool (-21°C)	NMP	Form II
59	Evaporation	NMP	Form II
60	Anti-Solvent (IPA) Addition Elevated Temperature	NMP	Form II
61	Anti-Solvent (IPA) Addition Ambient Temperature	NMP	Form II
62	Anti-Solvent (IPA) Addition (4°C)	NMP	Form II
63	Anti-Solvent (IPA) Addition (-21°C)	NMP	Form II
64	Anti-Solvent (Ethanol) Addition Ambient Temperature	NMP	Form II
65	Anti-Solvent (Ethanol) Addition (4°C)	NMP	Form I / II
66	Anti-Solvent (Ethanol) Addition (-21°C)	NMP	Form II
67	Temp. Cycling	EtOAc/cyclohexane (1:2)	Form II
68	Controlled Cool (4°C)	EtOAc/cyclohexane (1:2)	No Solid
69	Controlled Cool (-21°C)	EtOAc/cyclohexane (1:2)	No Solid
70	Evaporation	EtOAc/cyclohexane (1:2)	Form II
71	Anti-Solvent (IPA) Addition Elevated Temperature	EtOAc/cyclohexane (1:2)	Form II
72	Anti-Solvent (IPA) Addition Ambient Temperature	EtOAc/cyclohexane (1:2)	Form II
73	Anti-Solvent (IPA) Addition (4°C)	EtOAc/cyclohexane (1:2)	Form II
74	Anti-Solvent (IPA) Addition (-21°C)	EtOAc/cyclohexane (1:2)	Form II
75	Anti-Solvent (Ethanol) Addition Ambient Temperature	EtOAc/cyclohexane (1:2)	Form II
76	Anti-Solvent (Ethanol) Addition (4°C)	EtOAc/cyclohexane (1:2)	Form I
77	Anti-Solvent (Ethanol) Addition (-21°C)	EtOAc/cyclohexane (1:2)	Form I / II

Test	Crystallization Method	Solvent	Results
78	Temp. Cycling	etOAc/toluene (1:2)	Form II
79	Controlled Cool (4°C)	etOAc/toluene (1:2)	No Solid
80	Controlled Cool (-21°C)	etOAc/toluene (1:2)	Form II
81	Evaporation	etOAc/toluene (1:2)	Form II
82	Anti-Solvent (IPA) Addition Elevated Temperature	etOAc/toluene (1:2)	Form II
83	Anti-Solvent (IPA) Addition Ambient Temperature	etOAc/toluene (1:2)	Form II
84	Anti-Solvent (IPA) Addition (4°C)	etOAc/toluene (1:2)	Form II
85	Anti-Solvent (IPA) Addition (-21°C)	etOAc/toluene (1:2)	Form II
86	Anti-Solvent (Ethanol) Addition Ambient Temperature	etOAc/toluene (1:2)	Form II
87	Anti-Solvent (Ethanol) Addition (4°C)	etOAc/toluene (1:2)	Form I
88	Anti-Solvent (Ethanol) Addition (-21°C)	etOAc/toluene (1:2)	Form II
89	Temp. Cycling	IPA/diisopropyl ether (1:2)	Form II
90	Controlled Cool (4°C)	IPA/diisopropyl ether (1:2)	Form V
91	Controlled Cool (-21°C)	IPA/diisopropyl ether (1:2)	Form II
92	Evaporation	IPA/diisopropyl ether (1:2)	Form II
93	Anti-Solvent (IPA) Addition Elevated Temperature	IPA/diisopropyl ether (1:2)	Form II
94	Anti-Solvent (IPA) Addition Ambient Temperature	IPA/diisopropyl ether (1:2)	Form II
95	Anti-Solvent (IPA) Addition (4°C)	IPA/diisopropyl ether (1:2)	Form II
96	Anti-Solvent (IPA) Addition (-21°C)	IPA/diisopropyl ether (1:2)	Form II
97	Anti-Solvent (Ethanol) Addition Ambient Temperature	IPA/diisopropyl ether (1:2)	Form II
98	Anti-Solvent (Ethanol) Addition (4°C)	IPA/diisopropyl ether (1:2)	Form I
99	Anti-Solvent (Ethanol) Addition (-21°C)	IPA/diisopropyl ether (1:2)	Form I / II
100	Temp. Cycling	DIPE	Form II
101	Controlled Cool (4°C)	DIPE	No Solid
102	Controlled Cool (-21°C)	DIPE	Form V
103	Evaporation	DIPE	Form II
104	Anti-Solvent (IPA) Addition Elevated Temperature	DIPE	Form II
105	Anti-Solvent (IPA) Addition Ambient Temperature	DIPE	Form II
106	Anti-Solvent (IPA)	DIPE	Form II

Test	Crystallization Method	Solvent	Results
	Addition (4°C)		
107	Anti-Solvent (IPA) Addition (-21°C)	DIPE	Form II
108	Anti-Solvent (Ethanol) Addition Ambient Temperature	DIPE	Form II
109	Anti-Solvent (Ethanol) Addition (4°C)	DIPE	Form I
110	Anti-Solvent (Ethanol) Addition (-21°C)	DIPE	Form II
111	Temp. Cycling	nitromethane/water (20%)	No Solid
112	Controlled Cool (4°C)	nitromethane/water (20%)	No Solid
113	Controlled Cool (-21°C)	nitromethane/water (20%)	No Solid
114	Evaporation	nitromethane/water (20%)	Form II
115	Anti-Solvent (IPA) Addition Elevated Temperature	nitromethane/water (20%)	No Solid
116	Anti-Solvent (IPA) Addition Ambient Temperature	nitromethane/water (20%)	Form II
117	Anti-Solvent (IPA) Addition (4°C)	nitromethane/water (20%)	Form II
118	Anti-Solvent (IPA) Addition (-21°C)	nitromethane/water (20%)	Form II
119	Anti-Solvent (Ethanol) Addition Ambient Temperature	nitromethane/water (20%)	Form II
120	Anti-Solvent (Ethanol) Addition (4°C)	nitromethane/water (20%)	Form I
121	Anti-Solvent (Ethanol) Addition (-21°C)	nitromethane/water (20%)	Form I / II
122	Temp. Cycling	acetone/water (20%)	No Solid
123	Controlled Cool (4°C)	acetone/water (20%)	Form II
124	Controlled Cool (-21°C)	acetone/water (20%)	Form II
125	Evaporation	acetone/water (20%)	Form II
126	Anti-Solvent (IPA) Addition Elevated Temperature	acetone/water (20%)	Form II
127	Anti-Solvent (IPA) Addition Ambient Temperature	acetone/water (20%)	Form II
128	Anti-Solvent (IPA) Addition (4°C)	acetone/water (20%)	Form II
129	Anti-Solvent (IPA) Addition (-21°C)	acetone/water (20%)	Form II
130	Anti-Solvent (Ethanol) Addition Ambient Temperature	acetone/water (20%)	Form II
131	Anti-Solvent (Ethanol) Addition (4°C)	acetone/water (20%)	Form I
132	Anti-Solvent (Ethanol) Addition (-21°C)	acetone/water (20%)	Form II
133	Temp. Cycling	1,4 dioxane/water	Form II

Test	Crystallization Method	Solvent	Results
		(20%)	
134	Controlled Cool (4°C)	1,4 dioxane/water (20%)	Form II
135	Controlled Cool (-21°C)	1,4 dioxane/water (20%)	No Solid
136	Evaporation	1,4 dioxane/water (20%)	Form II
137	Anti-Solvent (IPA) Addition Elevated Temperature	1,4 dioxane/water (20%)	Form II
138	Anti-Solvent (IPA) Addition Ambient Temperature	1,4 dioxane/water (20%)	Form II
139	Anti-Solvent (IPA) Addition (4°C)	1,4 dioxane/water (20%)	Form II
140	Anti-Solvent (IPA) Addition (-21°C)	1,4 dioxane/water (20%)	Form II
141	Anti-Solvent (Ethanol) Addition Ambient Temperature	1,4 dioxane/water (20%)	Form II
142	Anti-Solvent (Ethanol) Addition (4°C)	1,4 dioxane/water (20%)	Form I
143	Anti-Solvent (Ethanol) Addition (-21°C)	1,4 dioxane/water (20%)	Form II
144	Temp. Cycling	diethyl ether	Form II
145	Controlled Cool (4°C)	diethyl ether	No Solid
146	Controlled Cool (-21°C)	diethyl ether	No Solid
147	Evaporation	diethyl ether	Form II
148	Anti-Solvent (IPA) Addition Elevated Temperature	diethyl ether	Form II
149	Anti-Solvent (IPA) Addition Ambient Temperature	diethyl ether	Form II
150	Anti-Solvent (IPA) Addition (4°C)	diethyl ether	Form II
151	Anti-Solvent (IPA) Addition (-21°C)	diethyl ether	Form II
152	Anti-Solvent (Ethanol) Addition Ambient Temperature	diethyl ether	Form II
153	Anti-Solvent (Ethanol) Addition (4°C)	diethyl ether	Form I
154	Anti-Solvent (Ethanol) Addition (-21°C)	diethyl ether	Form I / II
155	Temp. Cycling	ethylene glycol	Form II
156	Controlled Cool (4°C)	ethylene glycol	No Solid
157	Controlled Cool (-21°C)	ethylene glycol	No Solid
158	Evaporation	ethylene glycol	No Solid
159	Anti-Solvent (IPA) Addition Elevated Temperature	ethylene glycol	Form II
160	Anti-Solvent (IPA) Addition Ambient Temperature	ethylene glycol	Form II
161	Anti-Solvent (IPA) Addition (4°C)	ethylene glycol	Form II

Test	Crystallization Method	Solvent	Results
162	Anti-Solvent (IPA) Addition (-21°C)	ethylene glycol	Form II
163	Anti-Solvent (Ethanol) Addition Ambient Temperature	ethylene glycol	Form II
164	Anti-Solvent (Ethanol) Addition (4°C)	ethylene glycol	Form II
165	Anti-Solvent (Ethanol) Addition (-21°C)	ethylene glycol	Form II
166	Temp. Cycling	meOAc/water (20%)	No Solid
167	Controlled Cool (4°C)	meOAc/water (20%)	No Solid
168	Controlled Cool (-21°C)	meOAc/water (20%)	No Solid
169	Evaporation	meOAc/water (20%)	Form II
170	Anti-Solvent (IPA) Addition Elevated Temperature	meOAc/water (20%)	Form II
171	Anti-Solvent (IPA) Addition Ambient Temperature	meOAc/water (20%)	Form II
172	Anti-Solvent (IPA) Addition (4°C)	meOAc/water (20%)	Form II
173	Anti-Solvent (IPA) Addition (-21°C)	meOAc/water (20%)	Form II
174	Anti-Solvent (Ethanol) Addition Ambient Temperature	meOAc/water (20%)	Form II
175	Anti-Solvent (Ethanol) Addition (4°C)	meOAc/water (20%)	Form I / II
176	Anti-Solvent (Ethanol) Addition (-21°C)	meOAc/water (20%)	Form II
177	Temp. Cycling	meOH/acetone (50:50)	Form II
178	Controlled Cool (4°C)	meOH/acetone (50:50)	No Solid
179	Controlled Cool (-21°C)	meOH/acetone (50:50)	No Solid
180	Evaporation	meOH/acetone (50:50)	Form II
181	Anti-Solvent (IPA) Addition Elevated Temperature	meOH/acetone (50:50)	Form II
182	Anti-Solvent (IPA) Addition Ambient Temperature	meOH/acetone (50:50)	Form II
183	Anti-Solvent (IPA) Addition (4°C)	meOH/acetone (50:50)	Form II
184	Anti-Solvent (IPA) Addition (-21°C)	meOH/acetone (50:50)	Form II
185	Anti-Solvent (Ethanol) Addition Ambient Temperature	meOH/acetone (50:50)	Form II
186	Anti-Solvent (Ethanol) Addition (4°C)	meOH/acetone (50:50)	Form I
187	Anti-Solvent (Ethanol) Addition (-21°C)	meOH/acetone (50:50)	Form I / II
188	Temp. Cycling	DMF	Form II
189	Controlled Cool (4°C)	DMF	Form II

Test	Crystallization Method	Solvent	Results
190	Controlled Cool (-21°C)	DMF	Form II
191	Evaporation	DMF	Form II
192	Anti-Solvent (IPA) Addition Elevated Temperature	DMF	Form II
193	Anti-Solvent (IPA) Addition Ambient Temperature	DMF	Form II
194	Anti-Solvent (IPA) Addition (4°C)	DMF	Form II
195	Anti-Solvent (IPA) Addition (-21°C)	DMF	Form II
196	Anti-Solvent (Ethanol) Addition Ambient Temperature	DMF	Form II
197	Anti-Solvent (Ethanol) Addition (4°C)	DMF	Form I / II
198	Anti-Solvent (Ethanol) Addition (-21°C)	DMF	Form II
199	Temp. Cycling	2-butanol	Form II
200	Controlled Cool (4°C)	2-butanol	No Solid
201	Controlled Cool (-21°C)	2-butanol	No Solid
202	Evaporation	2-butanol	Form II
203	Anti-Solvent (IPA) Addition Elevated Temperature	2-butanol	Form III
204	Anti-Solvent (IPA) Addition Ambient Temperature	2-butanol	Form II
205	Anti-Solvent (IPA) Addition (4°C)	2-butanol	Form II
206	Anti-Solvent (IPA) Addition (-21°C)	2-butanol	Form II
207	Anti-Solvent (Ethanol) Addition Ambient Temperature	2-butanol	Form II
208	Anti-Solvent (Ethanol) Addition (4°C)	2-butanol	Form I / II
209	Anti-Solvent (Ethanol) Addition (-21°C)	2-butanol	Form I / II
210	Temp. Cycling	cumene	Form II
211	Controlled Cool (4°C)	cumene	No Solid
212	Controlled Cool (-21°C)	cumene	No Solid
213	Evaporation	cumene	Form II
214	Anti-Solvent (IPA) Addition Elevated Temperature	cumene	Form II
215	Anti-Solvent (IPA) Addition Ambient Temperature	cumene	Form II
216	Anti-Solvent (IPA) Addition (4°C)	cumene	Form II
217	Anti-Solvent (IPA) Addition (-21°C)	cumene	Form II
218	Anti-Solvent (Ethanol) Addition Ambient Temperature	cumene	Form II

Test	Crystallization Method	Solvent	Results
219	Anti-Solvent (Ethanol) Addition (4°C)	cumene	Form II
220	Anti-Solvent (Ethanol) Addition (-21°C)	cumene	Form I / II
221	Temp. Cycling	ethyl formate	Form II
222	Controlled Cool (4°C)	ethyl formate	No Solid
223	Controlled Cool (-21°C)	ethyl formate	Form II
224	Evaporation	ethyl formate	Form II
225	Anti-Solvent (IPA) Addition Elevated Temperature	ethyl formate	Form II
226	Anti-Solvent (IPA) Addition Ambient Temperature	ethyl formate	Form II
227	Anti-Solvent (IPA) Addition (4°C)	ethyl formate	Form II
228	Anti-Solvent (IPA) Addition (-21°C)	ethyl formate	Form II
229	Anti-Solvent (Ethanol) Addition Ambient Temperature	ethyl formate	Form II
230	Anti-Solvent (Ethanol) Addition (4°C)	ethyl formate	Form I
231	Anti-Solvent (Ethanol) Addition (-21°C)	ethyl formate	Form I / II
232	Temp. Cycling	isobutyl acetate	Form II
233	Controlled Cool (4°C)	isobutyl acetate	No Solid
234	Controlled Cool (-21°C)	isobutyl acetate	Form II
235	Evaporation	isobutyl acetate	No Solid
236	Anti-Solvent (IPA) Addition Elevated Temperature	isobutyl acetate	Form II
237	Anti-Solvent (IPA) Addition Ambient Temperature	isobutyl acetate	Form II
238	Anti-Solvent (IPA) Addition (4°C)	isobutyl acetate	Form II
239	Anti-Solvent (IPA) Addition (-21°C)	isobutyl acetate	Form III
240	Anti-Solvent (Ethanol) Addition Ambient Temperature	isobutyl acetate	Form II
241	Anti-Solvent (Ethanol) Addition (4°C)	isobutyl acetate	Form II
242	Anti-Solvent (Ethanol) Addition (-21°C)	isobutyl acetate	Form I / II
243	Temp. Cycling	3-methyl-1-butanol	Form II
244	Controlled Cool (4°C)	3-methyl-1-butanol	No Solid
245	Controlled Cool (-21°C)	3-methyl-1-butanol	No Solid
246	Evaporation	3-methyl-1-butanol	Form II
247	Anti-Solvent (IPA) Addition Elevated Temperature	3-methyl-1-butanol	Form II
248	Anti-Solvent (IPA) Addition Ambient Temperature	3-methyl-1-butanol	Form II
249	Anti-Solvent (IPA)	3-methyl-1-butanol	Form II

Test	Crystallization Method	Solvent	Results
	Addition (4°C)		
250	Anti-Solvent (IPA) Addition (-21°C)	3-methyl-1-butanol	Form II
251	Anti-Solvent (Ethanol) Addition Ambient Temperature	3-methyl-1-butanol	Form II
252	Anti-Solvent (Ethanol) Addition (4°C)	3-methyl-1-butanol	Form I / II
253	Anti-Solvent (Ethanol) Addition (-21°C)	3-methyl-1-butanol	Form I / II
254	Temp. Cycling	anisole	Form II
255	Controlled Cool (4°C)	anisole	No Solid
256	Controlled Cool (-21°C)	anisole	Form II
257	Evaporation	anisole	Form II
258	Anti-Solvent (IPA) Addition Elevated Temperature	anisole	Form II
259	Anti-Solvent (IPA) Addition Ambient Temperature	anisole	Form II
260	Anti-Solvent (IPA) Addition (4°C)	anisole	Form II
261	Anti-Solvent (IPA) Addition (-21°C)	anisole	Form II / IV
262	Anti-Solvent (Ethanol) Addition Ambient Temperature	anisole	Form II
263	Anti-Solvent (Ethanol) Addition (4°C)	anisole	Form II
264	Anti-Solvent (Ethanol) Addition (-21°C)	anisole	Form I
265	Temp. Cycling	IPA/isopropyl acetate (1:2)	Form II
266	Controlled Cool (4°C)	IPA/isopropyl acetate (1:2)	No Solid
267	Controlled Cool (-21°C)	IPA/isopropyl acetate (1:2)	No Solid
268	Evaporation	IPA/isopropyl acetate (1:2)	Form II
269	Anti-Solvent (IPA) Addition Elevated Temperature	IPA/isopropyl acetate (1:2)	Form II
270	Anti-Solvent (IPA) Addition Ambient Temperature	IPA/isopropyl acetate (1:2)	Form II
271	Anti-Solvent (IPA) Addition (4°C)	IPA/isopropyl acetate (1:2)	Form II
272	Anti-Solvent (IPA) Addition (-21°C)	IPA/isopropyl acetate (1:2)	Form II
273	Anti-Solvent (Ethanol) Addition Ambient Temperature	IPA/isopropyl acetate (1:2)	Form II
274	Anti-Solvent (Ethanol) Addition (4°C)	IPA/isopropyl acetate (1:2)	Form II
275	Anti-Solvent (Ethanol) Addition (-21°C)	IPA/isopropyl acetate (1:2)	Form I
276	Temp. Cycling	EtOH: 1% H ₂ O	Form II

Test	Crystallization Method	Solvent	Results
277	Controlled Cool (4°C)	EtOH: 1% H ₂ O	No Solid
278	Controlled Cool (-21°C)	EtOH: 1% H ₂ O	No Solid
279	Evaporation	EtOH: 1% H ₂ O	No Solid
280	Anti-Solvent (IPA) Addition Elevated Temperature	EtOH: 1% H ₂ O	No Solid
281	Anti-Solvent (IPA) Addition Ambient Temperature	EtOH: 1% H ₂ O	No Solid
282	Anti-Solvent (IPA) Addition (4°C)	EtOH: 1% H ₂ O	No Solid
283	Anti-Solvent (IPA) Addition (-21°C)	EtOH: 1% H ₂ O	No Solid
284	Anti-Solvent (Ethanol) Addition Ambient Temperature	EtOH: 1% H ₂ O	No Solid
285	Anti-Solvent (Ethanol) Addition (4°C)	EtOH: 1% H ₂ O	No Solid
286	Anti-Solvent (Ethanol) Addition (-21°C)	EtOH: 1% H ₂ O	No Solid
287	Temp. Cycling	EtOH: 3% H ₂ O	Form II
288	Controlled Cool (4°C)	EtOH: 3% H ₂ O	No Solid
289	Controlled Cool (-21°C)	EtOH: 3% H ₂ O	No Solid
290	Evaporation	EtOH: 3% H ₂ O	No Solid
291	Anti-Solvent (IPA) Addition Elevated Temperature	EtOH: 3% H ₂ O	No Solid
292	Anti-Solvent (IPA) Addition Ambient Temperature	EtOH: 3% H ₂ O	No Solid
293	Anti-Solvent (IPA) Addition (4°C)	EtOH: 3% H ₂ O	No Solid
294	Anti-Solvent (IPA) Addition (-21°C)	EtOH: 3% H ₂ O	No Solid
295	Anti-Solvent (Ethanol) Addition Ambient Temperature	EtOH: 3% H ₂ O	No Solid
296	Anti-Solvent (Ethanol) Addition (4°C)	EtOH: 3% H ₂ O	No Solid
297	Anti-Solvent (Ethanol) Addition (-21°C)	EtOH: 3% H ₂ O	No Solid
298	Temp. Cycling	EtOH: 5% H ₂ O	Form II
299	Controlled Cool (4°C)	EtOH: 5% H ₂ O	No Solid
300	Controlled Cool (-21°C)	EtOH: 5% H ₂ O	No Solid
301	Evaporation	EtOH: 5% H ₂ O	Form II
302	Anti-Solvent (IPA) Addition Elevated Temperature	EtOH: 5% H ₂ O	No Solid
303	Anti-Solvent (IPA) Addition Ambient Temperature	EtOH: 5% H ₂ O	Form II
304	Anti-Solvent (IPA) Addition (4°C)	EtOH: 5% H ₂ O	No Solid
305	Anti-Solvent (IPA) Addition (-21°C)	EtOH: 5% H ₂ O	No Solid
306	Anti-Solvent (Ethanol) Addition Ambient	EtOH: 5% H ₂ O	No Solid

Test	Crystallization Method	Solvent	Results
	Temperature		
307	Anti-Solvent (Ethanol) Addition (4°C)	EtOH: 5% H ₂ O	No Solid
308	Anti-Solvent (Ethanol) Addition (-21°C)	EtOH: 5% H ₂ O	No Solid
309	Temp. Cycling	IPA: 1% H ₂ O	Form II
310	Controlled Cool (4°C)	IPA: 1% H ₂ O	No Solid
311	Controlled Cool (-21°C)	IPA: 1% H ₂ O	No Solid
312	Evaporation	IPA: 1% H ₂ O	No Solid
313	Anti-Solvent (IPA) Addition Elevated Temperature	IPA: 1% H ₂ O	No Solid
314	Anti-Solvent (IPA) Addition Ambient Temperature	IPA: 1% H ₂ O	No Solid
315	Anti-Solvent (IPA) Addition (4°C)	IPA: 1% H ₂ O	No Solid
316	Anti-Solvent (IPA) Addition (-21°C)	IPA: 1% H ₂ O	No Solid
317	Anti-Solvent (Ethanol) Addition Ambient Temperature	IPA: 1% H ₂ O	No Solid
318	Anti-Solvent (Ethanol) Addition (4°C)	IPA: 1% H ₂ O	No Solid
319	Anti-Solvent (Ethanol) Addition (-21°C)	IPA: 1% H ₂ O	No Solid
320	Temp. Cycling	IPA: 3% H ₂ O	Form II
321	Controlled Cool (4°C)	IPA: 3% H ₂ O	No Solid
322	Controlled Cool (-21°C)	IPA: 3% H ₂ O	No Solid
323	Evaporation	IPA: 3% H ₂ O	No Solid
324	Anti-Solvent (IPA) Addition Elevated Temperature	IPA: 3% H ₂ O	No Solid
325	Anti-Solvent (IPA) Addition Ambient Temperature	IPA: 3% H ₂ O	No Solid
326	Anti-Solvent (IPA) Addition (4°C)	IPA: 3% H ₂ O	No Solid
327	Anti-Solvent (IPA) Addition (-21°C)	IPA: 3% H ₂ O	No Solid
328	Anti-Solvent (Ethanol) Addition Ambient Temperature	IPA: 3% H ₂ O	No Solid
329	Anti-Solvent (Ethanol) Addition (4°C)	IPA: 3% H ₂ O	No Solid
330	Anti-Solvent (Ethanol) Addition (-21°C)	IPA: 3% H ₂ O	No Solid
331	Temp. Cycling	IPA: 5% H ₂ O	Form II
332	Controlled Cool (4°C)	IPA: 5% H ₂ O	No Solid
333	Controlled Cool (-21°C)	IPA: 5% H ₂ O	No Solid
334	Evaporation	IPA: 5% H ₂ O	Form II
335	Anti-Solvent (IPA) Addition Elevated Temperature	IPA: 5% H ₂ O	No Solid
336	Anti-Solvent (IPA) Addition Ambient Temperature	IPA: 5% H ₂ O	No Solid

Test	Crystallization Method	Solvent	Results
337	Anti-Solvent (IPA) Addition (4°C)	IPA: 5% H ₂ O	No Solid
338	Anti-Solvent (IPA) Addition (-21°C)	IPA: 5% H ₂ O	No Solid
339	Anti-Solvent (Ethanol) Addition Ambient Temperature	IPA: 5% H ₂ O	No Solid
340	Anti-Solvent (Ethanol) Addition (4°C)	IPA: 5% H ₂ O	No Solid
341	Anti-Solvent (Ethanol) Addition (-21°C)	IPA: 5% H ₂ O	No Solid
342	Temp. Cycling	ACN: 1% H ₂ O	Form II
343	Controlled Cool (4°C)	ACN: 1% H ₂ O	No Solid
344	Controlled Cool (-21°C)	ACN: 1% H ₂ O	No Solid
345	Evaporation	ACN: 1% H ₂ O	Form II
346	Anti-Solvent (IPA) Addition Elevated Temperature	ACN: 1% H ₂ O	No Solid
347	Anti-Solvent (IPA) Addition Ambient Temperature	ACN: 1% H ₂ O	No Solid
348	Anti-Solvent (IPA) Addition (4°C)	ACN: 1% H ₂ O	No Solid
349	Anti-Solvent (IPA) Addition (-21°C)	ACN: 1% H ₂ O	No Solid
350	Anti-Solvent (Ethanol) Addition Ambient Temperature	ACN: 1% H ₂ O	No Solid
351	Anti-Solvent (Ethanol) Addition (4°C)	ACN: 1% H ₂ O	No Solid
352	Anti-Solvent (Ethanol) Addition (-21°C)	ACN: 1% H ₂ O	No Solid
353	Temp. Cycling	ACN: 6% H ₂ O	Form II
354	Controlled Cool (4°C)	ACN: 6% H ₂ O	No Solid
355	Controlled Cool (-21°C)	ACN: 6% H ₂ O	No Solid
356	Evaporation	ACN: 6% H ₂ O	Form II
357	Anti-Solvent (IPA) Addition Elevated Temperature	ACN: 6% H ₂ O	No Solid
358	Anti-Solvent (IPA) Addition Ambient Temperature	ACN: 6% H ₂ O	No Solid
359	Anti-Solvent (IPA) Addition (4°C)	ACN: 6% H ₂ O	No Solid
360	Anti-Solvent (IPA) Addition (-21°C)	ACN: 6% H ₂ O	No Solid
361	Anti-Solvent (Ethanol) Addition Ambient Temperature	ACN: 6% H ₂ O	No Solid
362	Anti-Solvent (Ethanol) Addition (4°C)	ACN: 6% H ₂ O	No Solid
363	Anti-Solvent (Ethanol) Addition (-21°C)	ACN: 6% H ₂ O	No Solid
364	Temp. Cycling	ACN: 12% H ₂ O	No Solid
365	Controlled Cool (4°C)	ACN: 12% H ₂ O	No Solid
366	Controlled Cool (-21°C)	ACN: 12% H ₂ O	No Solid
367	Evaporation	ACN: 12% H ₂ O	Form II

Test	Crystallization Method	Solvent	Results
368	Anti-Solvent (IPA) Addition Elevated Temperature	ACN: 12% H ₂ O	No Solid
369	Anti-Solvent (IPA) Addition Ambient Temperature	ACN: 12% H ₂ O	Form II
370	Anti-Solvent (IPA) Addition (4°C)	ACN: 12% H ₂ O	No Solid
371	Anti-Solvent (IPA) Addition (-21°C)	ACN: 12% H ₂ O	Form II
372	Anti-Solvent (Ethanol) Addition Ambient Temperature	ACN: 12% H ₂ O	No Solid
373	Anti-Solvent (Ethanol) Addition (4°C)	ACN: 12% H ₂ O	No Solid
374	Anti-Solvent (Ethanol) Addition (-21°C)	ACN: 12% H ₂ O	No Solid
375	Temp. Cycling	DMF: 5% H ₂ O	Form II
376	Controlled Cool (4°C)	DMF: 5% H ₂ O	No Solid
377	Controlled Cool (-21°C)	DMF: 5% H ₂ O	No Solid
378	Evaporation	DMF: 5% H ₂ O	No Solid
379	Anti-Solvent (IPA) Addition Elevated Temperature	DMF: 5% H ₂ O	No Solid
380	Anti-Solvent (IPA) Addition Ambient Temperature	DMF: 5% H ₂ O	No Solid
381	Anti-Solvent (IPA) Addition (4°C)	DMF: 5% H ₂ O	No Solid
382	Anti-Solvent (IPA) Addition (-21°C)	DMF: 5% H ₂ O	No Solid
383	Anti-Solvent (Ethanol) Addition Ambient Temperature	DMF: 5% H ₂ O	No Solid
384	Anti-Solvent (Ethanol) Addition (4°C)	DMF: 5% H ₂ O	No Solid
385	Anti-Solvent (Ethanol) Addition (-21°C)	DMF: 5% H ₂ O	No Solid
386	Temp. Cycling	DMF: 15% H ₂ O	Form II
387	Controlled Cool (4°C)	DMF: 15% H ₂ O	No Solid
388	Controlled Cool (-21°C)	DMF: 15% H ₂ O	No Solid
389	Evaporation	DMF: 15% H ₂ O	No Solid
390	Anti-Solvent (IPA) Addition Elevated Temperature	DMF: 15% H ₂ O	No Solid
391	Anti-Solvent (IPA) Addition Ambient Temperature	DMF: 15% H ₂ O	No Solid
392	Anti-Solvent (IPA) Addition (4°C)	DMF: 15% H ₂ O	No Solid
393	Anti-Solvent (IPA) Addition (-21°C)	DMF: 15% H ₂ O	No Solid
394	Anti-Solvent (Ethanol) Addition Ambient Temperature	DMF: 15% H ₂ O	No Solid
395	Anti-Solvent (Ethanol) Addition (4°C)	DMF: 15% H ₂ O	No Solid

Test	Crystallization Method	Solvent	Results
396	Anti-Solvent (Ethanol) Addition (-21°C)	DMF: 15% H ₂ O	No Solid
397	Temp. Cycling	DMF: 30% H ₂ O	Form II
398	Controlled Cool (4°C)	DMF: 30% H ₂ O	Form II
399	Controlled Cool (-21°C)	DMF: 30% H ₂ O	Form II
400	Evaporation	DMF: 30% H ₂ O	Form II
401	Anti-Solvent (IPA) Addition Elevated Temperature	DMF: 30% H ₂ O	Form II
402	Anti-Solvent (IPA) Addition Ambient Temperature	DMF: 30% H ₂ O	Form II
403	Anti-Solvent (IPA) Addition (4°C)	DMF: 30% H ₂ O	Form II
404	Anti-Solvent (IPA) Addition (-21°C)	DMF: 30% H ₂ O	Form II
405	Anti-Solvent (Ethanol) Addition Ambient Temperature	DMF: 30% H ₂ O	Form II
406	Anti-Solvent (Ethanol) Addition (4°C)	DMF: 30% H ₂ O	No Solid
407	Anti-Solvent (Ethanol) Addition (-21°C)	DMF: 30% H ₂ O	Form II
408	Temp. Cycling	1,4-dioxane: 1% H ₂ O	Form II
409	Controlled Cool (4°C)	1,4-dioxane: 1% H ₂ O	No Solid
410	Controlled Cool (-21°C)	1,4-dioxane: 1% H ₂ O	No Solid
411	Evaporation	1,4-dioxane: 1% H ₂ O	No Solid
412	Anti-Solvent (IPA) Addition Elevated Temperature	1,4-dioxane: 1% H ₂ O	No Solid
413	Anti-Solvent (IPA) Addition Ambient Temperature	1,4-dioxane: 1% H ₂ O	No Solid
414	Anti-Solvent (IPA) Addition (4°C)	1,4-dioxane: 1% H ₂ O	No Solid
415	Anti-Solvent (IPA) Addition (-21°C)	1,4-dioxane: 1% H ₂ O	No Solid
416	Anti-Solvent (Ethanol) Addition Ambient Temperature	1,4-dioxane: 1% H ₂ O	No Solid
417	Anti-Solvent (Ethanol) Addition (4°C)	1,4-dioxane: 1% H ₂ O	No Solid
418	Anti-Solvent (Ethanol) Addition (-21°C)	1,4-dioxane: 1% H ₂ O	No Solid
419	Temp. Cycling	1,4-dioxane: 3% H ₂ O	Form II
420	Controlled Cool (4°C)	1,4-dioxane: 3% H ₂ O	No Solid
421	Controlled Cool (-21°C)	1,4-dioxane: 3% H ₂ O	No Solid
422	Evaporation	1,4-dioxane: 3% H ₂ O	Form II
423	Anti-Solvent (IPA) Addition Elevated Temperature	1,4-dioxane: 3% H ₂ O	No Solid
424	Anti-Solvent (IPA) Addition Ambient Temperature	1,4-dioxane: 3% H ₂ O	No Solid
425	Anti-Solvent (IPA) Addition (4°C)	1,4-dioxane: 3% H ₂ O	No Solid
426	Anti-Solvent (IPA)	1,4-dioxane: 3% H ₂ O	No Solid

Test	Crystallization Method	Solvent	Results
	Addition (-21°C)		
427	Anti-Solvent (Ethanol) Addition Ambient Temperature	1,4-dioxane: 3% H ₂ O	No Solid
428	Anti-Solvent (Ethanol) Addition (4°C)	1,4-dioxane: 3% H ₂ O	No Solid
429	Anti-Solvent (Ethanol) Addition (-21°C)	1,4-dioxane: 3% H ₂ O	No Solid
430	Temp. Cycling	1,4-dioxane: 10% H ₂ O	Form II
431	Controlled Cool (4°C)	1,4-dioxane: 10% H ₂ O	No Solid
432	Controlled Cool (-21°C)	1,4-dioxane: 10% H ₂ O	No Solid
433	Evaporation	1,4-dioxane: 10% H ₂ O	Form II
434	Anti-Solvent (IPA) Addition Elevated Temperature	1,4-dioxane: 10% H ₂ O	No Solid
435	Anti-Solvent (IPA) Addition Ambient Temperature	1,4-dioxane: 10% H ₂ O	No Solid
436	Anti-Solvent (IPA) Addition (4°C)	1,4-dioxane: 10% H ₂ O	No Solid
437	Anti-Solvent (IPA) Addition (-21°C)	1,4-dioxane: 10% H ₂ O	No Solid
438	Anti-Solvent (Ethanol) Addition Ambient Temperature	1,4-dioxane: 10% H ₂ O	No Solid
439	Anti-Solvent (Ethanol) Addition (4°C)	1,4-dioxane: 10% H ₂ O	No Solid
440	Anti-Solvent (Ethanol) Addition (-21°C)	1,4-dioxane: 10% H ₂ O	No Solid
441	Temp. Cycling	MeOH: 5% H ₂ O	Form II
442	Controlled Cool (4°C)	MeOH: 5% H ₂ O	No Solid
443	Controlled Cool (-21°C)	MeOH: 5% H ₂ O	No Solid
444	Evaporation	MeOH: 5% H ₂ O	Form II
445	Anti-Solvent (IPA) Addition Elevated Temperature	MeOH: 5% H ₂ O	Form II
446	Anti-Solvent (IPA) Addition Ambient Temperature	MeOH: 5% H ₂ O	Form II
447	Anti-Solvent (IPA) Addition (4°C)	MeOH: 5% H ₂ O	Form II
448	Anti-Solvent (IPA) Addition (-21°C)	MeOH: 5% H ₂ O	Form II
449	Anti-Solvent (Ethanol) Addition Ambient Temperature	MeOH: 5% H ₂ O	No Solid
450	Anti-Solvent (Ethanol) Addition (4°C)	MeOH: 5% H ₂ O	Form II
451	Anti-Solvent (Ethanol) Addition (-21°C)	MeOH: 5% H ₂ O	Form II
452	Temp. Cycling	MeOH: 20% H ₂ O	No Solid
453	Controlled Cool (4°C)	MeOH: 20% H ₂ O	Form II
454	Controlled Cool (-21°C)	MeOH: 20% H ₂ O	Form II
455	Evaporation	MeOH: 20% H ₂ O	Form II
456	Anti-Solvent (IPA) Addition Elevated Temperature	MeOH: 20% H ₂ O	Form II

Test	Crystallization Method	Solvent	Results
457	Anti-Solvent (IPA) Addition Ambient Temperature	MeOH: 20% H ₂ O	Form II
458	Anti-Solvent (IPA) Addition (4°C)	MeOH: 20% H ₂ O	Form II
459	Anti-Solvent (IPA) Addition (-21°C)	MeOH: 20% H ₂ O	Form II
460	Anti-Solvent (Ethanol) Addition Ambient Temperature	MeOH: 20% H ₂ O	Form II
461	Anti-Solvent (Ethanol) Addition (4°C)	MeOH: 20% H ₂ O	Form II
462	Anti-Solvent (Ethanol) Addition (-21°C)	MeOH: 20% H ₂ O	Form I / II
463	Temp. Cycling	MeOH: 50% H ₂ O	Form II
464	Controlled Cool (4°C)	MeOH: 50% H ₂ O	Form II
465	Controlled Cool (-21°C)	MeOH: 50% H ₂ O	Form II
466	Evaporation	MeOH: 50% H ₂ O	No Solid
467	Anti-Solvent (IPA) Addition Elevated Temperature	MeOH: 50% H ₂ O	Form II
468	Anti-Solvent (IPA) Addition Ambient Temperature	MeOH: 50% H ₂ O	No Solid
469	Anti-Solvent (IPA) Addition (4°C)	MeOH: 50% H ₂ O	Form II
470	Anti-Solvent (IPA) Addition (-21°C)	MeOH: 50% H ₂ O	No Solid
471	Anti-Solvent (Ethanol) Addition Ambient Temperature	MeOH: 50% H ₂ O	Form II
472	Anti-Solvent (Ethanol) Addition (4°C)	MeOH: 50% H ₂ O	Form I
473	Anti-Solvent (Ethanol) Addition (-21°C)	MeOH: 50% H ₂ O	Form I / II
474	Temp. Cycling	THF: 1% H ₂ O	Form II
475	Controlled Cool (4°C)	THF: 1% H ₂ O	No Solid
476	Controlled Cool (-21°C)	THF: 1% H ₂ O	No Solid
477	Evaporation	THF: 1% H ₂ O	Form II
478	Anti-Solvent (IPA) Addition Elevated Temperature	THF: 1% H ₂ O	No Solid
479	Anti-Solvent (IPA) Addition Ambient Temperature	THF: 1% H ₂ O	No Solid
480	Anti-Solvent (IPA) Addition (4°C)	THF: 1% H ₂ O	No Solid
481	Anti-Solvent (IPA) Addition (-21°C)	THF: 1% H ₂ O	No Solid
482	Anti-Solvent (Ethanol) Addition Ambient Temperature	THF: 1% H ₂ O	No Solid
483	Anti-Solvent (Ethanol) Addition (4°C)	THF: 1% H ₂ O	No Solid
484	Anti-Solvent (Ethanol) Addition (-21°C)	THF: 1% H ₂ O	No Solid
485	Temp. Cycling	THF: 3% H ₂ O	Form II

Test	Crystallization Method	Solvent	Results
486	Controlled Cool (4°C)	THF: 3% H ₂ O	No Solid
487	Controlled Cool (-21°C)	THF: 3% H ₂ O	No Solid
488	Evaporation	THF: 3% H ₂ O	No Solid
489	Anti-Solvent (IPA) Addition Elevated Temperature	THF: 3% H ₂ O	No Solid
490	Anti-Solvent (IPA) Addition Ambient Temperature	THF: 3% H ₂ O	Form II
491	Anti-Solvent (IPA) Addition (4°C)	THF: 3% H ₂ O	No Solid
492	Anti-Solvent (IPA) Addition (-21°C)	THF: 3% H ₂ O	No Solid
493	Anti-Solvent (Ethanol) Addition Ambient Temperature	THF: 3% H ₂ O	No Solid
494	Anti-Solvent (Ethanol) Addition (4°C)	THF: 3% H ₂ O	No Solid
495	Anti-Solvent (Ethanol) Addition (-21°C)	THF: 3% H ₂ O	No Solid
496	Temp. Cycling	THF: 5% H ₂ O	No Solid
497	Controlled Cool (4°C)	THF: 5% H ₂ O	No Solid
498	Controlled Cool (-21°C)	THF: 5% H ₂ O	No Solid
499	Evaporation	THF: 5% H ₂ O	Form II
500	Anti-Solvent (IPA) Addition Elevated Temperature	THF: 5% H ₂ O	No Solid
501	Anti-Solvent (IPA) Addition Ambient Temperature	THF: 5% H ₂ O	No Solid
502	Anti-Solvent (IPA) Addition (4°C)	THF: 5% H ₂ O	Form II
503	Anti-Solvent (IPA) Addition (-21°C)	THF: 5% H ₂ O	No Solid
504	Anti-Solvent (Ethanol) Addition Ambient Temperature	THF: 5% H ₂ O	No Solid
505	Anti-Solvent (Ethanol) Addition (4°C)	THF: 5% H ₂ O	No Solid
506	Anti-Solvent (Ethanol) Addition (-21°C)	THF: 5% H ₂ O	No Solid
507	Temp. Cycling	butan-1-ol: 1% H ₂ O	Form II
508	Controlled Cool (4°C)	butan-1-ol: 1% H ₂ O	No Solid
509	Controlled Cool (-21°C)	butan-1-ol: 1% H ₂ O	No Solid
510	Evaporation	butan-1-ol: 1% H ₂ O	Form II
511	Anti-Solvent (IPA) Addition Elevated Temperature	butan-1-ol: 1% H ₂ O	No Solid
512	Anti-Solvent (IPA) Addition Ambient Temperature	butan-1-ol: 1% H ₂ O	No Solid
513	Anti-Solvent (IPA) Addition (4°C)	butan-1-ol: 1% H ₂ O	No Solid
514	Anti-Solvent (IPA) Addition (-21°C)	butan-1-ol: 1% H ₂ O	No Solid
515	Anti-Solvent (Ethanol) Addition Ambient	butan-1-ol: 1% H ₂ O	No Solid

Test	Crystallization Method	Solvent	Results
	Temperature		
516	Anti-Solvent (Ethanol) Addition (4°C)	butan-1-ol: 1% H ₂ O	No Solid
517	Anti-Solvent (Ethanol) Addition (-21°C)	butan-1-ol: 1% H ₂ O	No Solid
518	Temp. Cycling	butan-1-ol: 3% H ₂ O	Form II
519	Controlled Cool (4°C)	butan-1-ol: 3% H ₂ O	No Solid
520	Controlled Cool (-21°C)	butan-1-ol: 3% H ₂ O	No Solid
521	Evaporation	butan-1-ol: 3% H ₂ O	Form II
522	Anti-Solvent (IPA) Addition Elevated Temperature	butan-1-ol: 3% H ₂ O	No Solid
523	Anti-Solvent (IPA) Addition Ambient Temperature	butan-1-ol: 3% H ₂ O	No Solid
524	Anti-Solvent (IPA) Addition (4°C)	butan-1-ol: 3% H ₂ O	No Solid
525	Anti-Solvent (IPA) Addition (-21°C)	butan-1-ol: 3% H ₂ O	No Solid
526	Anti-Solvent (Ethanol) Addition Ambient Temperature	butan-1-ol: 3% H ₂ O	No Solid
527	Anti-Solvent (Ethanol) Addition (4°C)	butan-1-ol: 3% H ₂ O	No Solid
528	Anti-Solvent (Ethanol) Addition (-21°C)	butan-1-ol: 3% H ₂ O	No Solid
529	Temp. Cycling	butan-1-ol: 5% H ₂ O	Form II
530	Controlled Cool (4°C)	butan-1-ol: 5% H ₂ O	No Solid
531	Controlled Cool (-21°C)	butan-1-ol: 5% H ₂ O	No Solid
532	Evaporation	butan-1-ol: 5% H ₂ O	Form II
533	Anti-Solvent (IPA) Addition Elevated Temperature	butan-1-ol: 5% H ₂ O	No Solid
534	Anti-Solvent (IPA) Addition Ambient Temperature	butan-1-ol: 5% H ₂ O	Form II
535	Anti-Solvent (IPA) Addition (4°C)	butan-1-ol: 5% H ₂ O	No Solid
536	Anti-Solvent (IPA) Addition (-21°C)	butan-1-ol: 5% H ₂ O	No Solid
537	Anti-Solvent (Ethanol) Addition Ambient Temperature	butan-1-ol: 5% H ₂ O	No Solid
538	Anti-Solvent (Ethanol) Addition (4°C)	butan-1-ol: 5% H ₂ O	No Solid
539	Anti-Solvent (Ethanol) Addition (-21°C)	butan-1-ol: 5% H ₂ O	No Solid
540	Temp. Cycling	1,4-dioxane	Form I
541	Evaporation	1,4-dioxane	Form I / II
542	Anti-Solvent Addition	1,4-dioxane	No Solid
543	Temp. Cycling	1-butanol	Form I
544	Evaporation	1-butanol	Form I / II
545	Anti-Solvent (Hexane) Addition (4°C)	1-butanol	Form III
546	Temp. Cycling	ethanol	Form I
547	Evaporation	ethanol	Form II
548	Anti-Solvent (Hexane)	ethanol	Form I

Test	Crystallization Method	Solvent	Results
	Addition (4°C)		
549	Temp. Cycling	acetone	Form I
550	Evaporation	acetone	Form II
551	Anti-Solvent (Hexane) Addition (4°C)	acetone	Form III
552	Temp. Cycling	benzonitrile	Form I
553	Evaporation	benzonitrile	Form II
554	Anti-Solvent (Hexane) Addition (4°C)	benzonitrile	Form II
555	Temp. Cycling	cyclohexane	Form I
556	Evaporation	cyclohexane	Form II
557	Anti-Solvent (Hexane) Addition (4°C)	cyclohexane	No Solid
558	Temp. Cycling	DCM	Form I
559	Evaporation	DCM	Form II
560	Anti-Solvent (Hexane) Addition (4°C)	DCM	Form III
561	Temp. Cycling	DMSO	Form I
562	Evaporation	DMSO	Form II / II
563	Anti-Solvent (Hexane) Addition (4°C)	DMSO	No Solid / No Solid
564	Temp. Cycling	EtOAc	Form I
565	Evaporation	EtOAc	Form II
566	Anti-Solvent (Hexane) Addition (4°C)	EtOAc	Form III
567	Temp. Cycling	Heptane	Form I
568	Evaporation	Heptane	Form I / II
569	Anti-Solvent (Hexane) Addition (4°C)	Heptane	No Solid / No Solid
570	Temp. Cycling	IPA	Form I
571	Evaporation	IPA	Form I / II
572	Anti-Solvent (Hexane) Addition (4°C)	IPA	No Solid
573	Temp. Cycling	IPA:Water (1%)	Form I
574	Evaporation	IPA:Water (1%)	Form II
575	Anti-Solvent (Hexane) Addition (4°C)	IPA:Water (1%)	No Solid / No Solid
576	Temp. Cycling	MeCN	Form I
577	Evaporation	MeCN	Form II
578	Anti-Solvent (Hexane) Addition (4°C)	MeCN	Form I / III
579	Temp. Cycling	MeCN:Water (1%)	Form I
580	Evaporation	MeCN:Water (1%)	Form I / II
581	Anti-Solvent (Hexane) Addition (4°C)	MeCN:Water (1%)	No Solid
582	Temp. Cycling	MEK	Form I
583	Evaporation	MEK	Form I / II
584	Anti-Solvent (Hexane) Addition (4°C)	MEK	Form III
585	Temp. Cycling	MeOAc	Form I
586	Evaporation	MeOAc	Form II
587	Anti-Solvent (Hexane) Addition (4°C)	MeOAc	Form III
588	Temp. Cycling	MeOH	Form I
589	Evaporation	MeOH	Form I / II
590	Anti-Solvent (Hexane)	MeOH	Form III

Test	Crystallization Method	Solvent	Results
	Addition (4°C)		
591	Temp. Cycling	MIBK	Form I
592	Evaporation	MIBK	Form II
593	Anti-Solvent (Hexane) Addition (4°C)	MIBK	No Solid
594	Temp. Cycling	Nitromethane	Form I
595	Evaporation	Nitromethane	Form II
596	Anti-Solvent (Hexane) Addition (4°C)	Nitromethane	Form I
597	Temp. Cycling	TBME	Form I
598	Evaporation	TBME	Form II
599	Anti-Solvent (Hexane) Addition (4°C)	TBME	Form I
600	Temp. Cycling	THF	Form I
601	Evaporation	THF	Form II
602	Anti-Solvent (Hexane) Addition (4°C)	THF	Form I / III
603	Temp. Cycling	THF:water (1%)	Form I
604	Evaporation	THF:water (1%)	Form I / II
605	Anti-Solvent (Hexane) Addition (4°C)	THF:water (1%)	No Solid
606	Temp. Cycling	toluene	Form I
607	Evaporation	toluene	Form II
608	Anti-Solvent (Hexane) Addition (4°C)	toluene	Form III
609	Temp. Cycling	water	No Solid
610	Evaporation	water	Form I / II
611	Anti-Solvent (Hexane) Addition (4°C)	water	Form III

Example 2: Intrinsic Dissolution Studies

[0242] The intrinsic dissolution rates for Forms I, II, and III were measured at pH conditions of 1.0, 4.5 and 6.7. The results are reproduced below in TABLE 6. In each case, complete dissolution was achieved in less than 3 minutes. Surprisingly, a pH dependence was observed for Form II; with the intrinsic dissolution rate increasing with the pH. In contrast, Forms I and III appear to dissolve at rates independent of pH.

TABLE 6 – Calculated Intrinsic Dissolution Rates (mg/cm²/s)

	1.0	4.5	6.7
Form I	0.41	0.44	0.37
Form II	0.26	0.34	0.62
Form III	0.49	0.44	0.45

Example 3: Solubility Studies

[0243] The solubility of L-ornithine phenyl acetate was approximated according to methods disclosed above. 24 solvents systems were tested: 1,4 dioxane, 1-butanol, ethanol, acetone, benzonitrile, cyclohexane, DCM, DMSO, EtOAc, Heptane, IPA, IPA (1% H₂O), MeCN, MeCN (1% H₂O), MEK, MeOAc, methanol, MIBK, Nitromethane, THF, THF (1% H₂O), Toluene and water. L-ornithine phenyl acetate exhibited a solubility in water, whereas L-ornithine phenyl acetate was substantially insoluble in the remaining solvent systems.

[0244] Slurries of L-ornithine phenyl acetate in water were also prepared and the slurry was filtered. The filtrate concentration was analyzed by HPLC, and the results show the solubility of L-ornithine phenyl acetate to be about 1.072 mg/mL.

[0245] HPLC determinations of solubility were also completed for five solvents: ethanol, acetone, methanol, DMSO and IPA. These results are summarized in TABLE 7.

TABLE 7 – HPLC Solubility Determinations

Solvent	Solubility (mg/mL)	Peak Area	Comments
EtOH	< 0.0033	N/A	Small peak
Acetone	0	0	API content beyond the lower limit of quantification (LLOQ)
MeOH	0.0033	1906.75	Resolved peak
DMSO	> 0.0033	N/A	Shoulder on DMSO peak
IPA	0	0	API content beyond the LLOQ

[0246] These results indicate that both acetone and IPA are suitable as anti-solvents for precipitating L-ornithine phenyl acetate. In contrast, solvents with measurable solubility are less favorable for precipitating crystalline forms of L-ornithine phenyl acetate.

[0247] Finally, the solubility of L-ornithine phenyl acetate was determined in various mixtures of IPA and water using HPLC. The results are shown in TABLE 8.

TABLE 8 – HPLC Solubility Determinations (IPA/Water)

% IPA	Peak Area	Solubility (mg/mL)
100	0	0
90	295	0.0054
80	2634	0.0455
70	8340	0.1433

Example 4: Small-scale Batch Process to Produce L-Ornithine Phenyl Acetate

[0248] About 8.4g (0.049moles) of L-ornithine HCl was dissolved in 42 mL H₂O and, separately, about 11.4g of silver benzoate was dissolved in 57mL DMSO. Subsequently, the silver benzoate solution was added to the L-ornithine HCl solution. Combining the two mixtures resulted in an immediate, exothermic precipitation of a creamy white solid (AgCl). The solid was removed by vacuum filtration and retaining the filtrate (L-ornithine benzoate in solution). 200mL of IPA was added to the filtrate and the mixture was cooled to 4°C. A crystalline solid precipitated after about 3 hours (L-ornithine benzoate) which was isolated by vacuum filtration. Yield: 60 %

[0249] 7.6 g (0.03moles) of the L-ornithine benzoate was dissolved in 38 mL H₂O and about 4.4g of sodium phenyl acetate was dissolved 22 mL H₂O. Subsequently, the sodium phenyl acetate solution was added to the L-ornithine benzoate solution and left to stir for about 10 minutes. About 240mL of IPA (8:2 IPA:H₂O) was added and the solution stirred for 30 minutes before cooling to 4°C. A crystalline solid precipitated after about 3 hrs at 4°C (L-ornithine phenyl acetate). The precipitate was isolated by vacuum filtration and washed with 48-144mL of IPA. Yield: 57 %

Example 5: Large-scale Batch Process to Produce L-Ornithine Phenyl Acetate

[0250] Two separate batch of L-ornithine phenyl acetate were prepared as follows:

[0251] About 75 Kg of L-Ornithine monohydrochloride was dissolved in 227 kg of water. To the resulting solution was added 102 Kg of silver benzoate dissolved in 266 kg of DMSO at room temperature within 2 hours. Initially, a strong exothermy was observed and the silver chloride precipitated. The receiver containing the solution was then washed with 14 Kg of DMSO that was added to the reaction mass. In order to remove the silver chloride formed, the reaction mass was filtered over a lens filter prepared with 10 kg of Celite and a GAF filter of 1mm. After filtration, the filter was washed with an additional 75 kg of water. The reaction mass was then heated at 35±2° C and 80 kg of sodium phenyl acetate was added. At this point the reaction mass was stirred at 35 ±2° C for at least 30 minutes.

[0252] In order to precipitate the final API, 353 kg of isopropyl alcohol was added to the reaction mass. The reaction mass was then cooled to 0±3°C within 6 hours, stirred for 1 hour and then the product isolated in a centrifuge.

[0253] About 86 kg of finished wet produce was obtained. The product was then dried at $40\pm 5^{\circ}\text{C}$ for about 6.5 to 8 hours to provide about 75 kg of L-ornithine phenyl acetate. Yield: 63.25. TABLE 9 summarizes measurements relating to the final product.

TABLE 9 – Analytical Results for Large-scale Batch Process

Test	Batch 1	Batch 2
Purity	98.80%	98.74%
Benzoate	0.17%	0.14%
Silver	28 ppm	157 ppm
Chloride	0.006%	0.005%
Sodium	7 ppm	26 ppm
Total Impurities	0.17%	0.14%
Physical Form	Form II	Form II

Example 6: Reducing Silver Content in L-Ornithine Phenyl Acetate

[0254] Batch 2 from Example 5 exhibited high amounts of silver (157 ppm), and therefore procedures were tested for reducing the silver content. Nine trials were completed; each generally including dissolving about 20 g of L-ornithine phenyl acetate from Batch 2 into 1.9 parts water, and then subsequently adding 10.8 parts IPA. A crystalline form was isolated at 0°C by filtration.

[0255] For four trials, 8.0 mg or 80 mg of heavy metal scavengers SMOPEX 102 or SMOPEX 112 were added to the aqueous solution and stirred for 2 hours. The scavengers failed to reduce the silver content below 126 ppm. Meanwhile, another trial applied the general conditions disclosed above and reduced the silver content to 179 ppm. In still another trial, the L-ornithine phenyl acetate was slurried in a solution of IPA, rather than crystallized; however this trial also failed to reduce the silver content below 144 ppm.

[0256] The last three trials included adding diluted HCl to the solution to precipitate remaining amount of silver as AgCl. The precipitate was then removed by filtration before The three trials included adding: (1) 1.0 g of 0.33% HCl at 20°C ; (2) 1.0 g of 0.33% HCl at 30°C ; and (3) 0.1 g of 3.3% HCl at 20°C . The three trials reduced the silver content to 30 ppm, 42 ppm, and 33 ppm, respectively, and each trial yielding greater

than 90% L-ornithine phenyl acetate. Accordingly, the addition of HCl was effective in reducing the amount of residual silver.

Example 6: Process for Preparing L-Ornithine Phenyl Acetate without an Intermediate Salt

[0257] As a general procedure, L-ornithine hydrochloride was suspended in a solvent. After that the reaction mass was heated and a base, sodium methoxide, was added. NaCl formed and was removed from the system by filtration. The reaction mass was cooled and a molar equivalent of phenyl acetic acid was added to the reaction mass in order to form L-ornithine phenyl acetate. The final product was isolated, washed and dried. A summary of the trial for this process is provided in TABLE 10.

TABLE 10 – Process Trials

Trial	Base	Eq. of Base	Solvent
1	NaOMe 21% in MeOH	1.0 eq.	MeOH
2	NaOMe 21% in MeOH	0.95 eq.	IPA
3	NaOMe 21% in EtOH	1.0 eq.	EtOH
4	NaOMe 21% in MeOH	1.0 eq.	MeOH
5	NaOMe 21% in MeOH	1.0 eq.	MeOH w/ IPA for precipitation
6	NaOMe 21% in MeOH	1.0 eq.	Acetonitrile
7	NaOMe 21% in MeOH	1.0 eq.	Water/IPA
8	NaOMe 21% in MeOH	1.0 eq.	Water/IPA
9	NaOMe 21% in MeOH	1.0 eq.	n-butanol

[0258] The resulting L-ornithine phenyl acetate was found to exhibit high amounts of chloride (at least about 1% by weight), and presumably include similar amounts of sodium. The yields were about 50% for Trials 2, 4, and 5.

Example 7: Thermal Stability Studies of Forms I, II, and III

[0259] Samples of Forms I, II and III were stored at increased temperatures and designated conditions as outlined in TABLE 11. The vacuum applied 600 psi to achieve the reduced pressure. The final compositions were tested by XRPD, NMR, IR and HPLC to determine any changes to the material.

[0260] Most notably, Form III does not transition to Form II under vacuum at 120° C, but rather exhibits greater chemical degradation compared to Forms I and II under

these conditions. Meanwhile, Form III converts to Form II and exhibits substantial chemical degradation at 120° C without a vacuum.

[0261] Form I converted to Form II in all the trials, but most interestingly, Form I exhibits substantial chemical degradation at 120° C without a vacuum. Thus, the conversion from Form I does not exhibit the same chemical stability as Form II, which is surprising considering the material readily converts to Form II.

[0262] Form II was stable and did not chemically degrade in all of the trials. Thus, Form II is the most stable. Meanwhile, Form III is more stable than Form I, but both forms exhibit substantial chemical degradation at 120° C without a vacuum.

TABLE 11 – Thermal Stability Trials

Trial	Initial Form	Temperature	Condition	Period	Results
1	Form I	80° C	no vacuum	7 days	Form II, no degradation
2	Form I	80° C	vacuum	7 days	Form II, no degradation
3	Form I	80° C	no vacuum	14 days	Form II, no degradation
4	Form I	80° C	vacuum	14 days	Form II, no degradation
5	Form II	80° C	no vacuum	7 days	Form II, no degradation
6	Form II	80° C	vacuum	7 days	Form II, no degradation
7	Form II	80° C	no vacuum	14 days	Form II, no degradation
8	Form II	80° C	vacuum	14 days	Form II, no degradation
5	Form III	80° C	no vacuum	7 days	Form III, no degradation
5	Form III	80° C	no vacuum	14 days	Form III, no degradation
6	Form I	120° C	no vacuum	7 days	Form II (>96% API)
7	Form I	120° C	vacuum	7 days	Form II (>99.9% API)
8	Form I	120° C	no vacuum	14 days	Form II (37% API)
9	Form I	120° C	vacuum	14 days	Form II (>96% API)
8	Form II	120° C	no vacuum	7 days	Form II (98.6% API)
9	Form II	120° C	vacuum	7 days	Form II (98.7% API)
10	Form II	120° C	no vacuum	14 days	Form II (>95% API)
11	Form II	120° C	vacuum	14 days	Form II (>95% API)
10	Form III	120° C	no vacuum	7 days	Form II (<30% API)
11	Form III	120° C	vacuum	7 days	Form III (>95% API)
12	Form III	120° C	no vacuum	14 days	Form II (<30% API)

Trial	Initial Form	Temperature	Condition	Period	Results
14	Form III	120° C	vacuum	14 days	Form III (88.8% API)

[0263] HPLC results for the trials exhibiting chemical degradation (e.g., Trial 10 from TABLE 11) are summarized in TABLE 12. Each degraded material exhibits common peaks at relative retention times (RRT) of 1.9, 2.2, 2.4, and 2.7, which suggests a common degradation pathway for different forms.

TABLE 12 – HPLC Results for Degraded Samples

HPLC ID	Sample ID	Form Tested	Stability Test	Timepoint (day)	Main Peak Retention Time (min)		Degradation/Impurity Peak(s)	
					Retention Time (min)	% Peak Area	Retention Time (min)	% Peak Area
39	W00045/45/3	III	120 °C ambient pressure	7	2.857	35.786	6.763	6.103
							7.562	45.161
42	W00045/45/6	III	120 °C under vacuum (ca. 600 psi)	7	2.787	88.885	7.598	9.389
51	W00045/45/1	I	120 °C ambient pressure	14	3.499	37.826	6.766	3.948
							7.569	42.525
							9.707	3.628
53	W00045/45/3	III	120 °C ambient pressure	14	3.476	30.394	6.763	5.975
							7.583	56.459
56	W00045/45/6	III	120 °C under vacuum (ca. 600 psi)	14	3.400	87.389	7.555	11.500

Example 8: Oxygen Stability Studies of Forms I, II, and III

[0264] Samples of Forms I, II and III were stored in 100% oxygen environments for 7 or 14 days and analyzed by NMR and IR. The results establish that Forms I and II show no signs of degradation after 14 days. Only IR results were completed for Form III at 7 days, and these results confirm there was no significant degradation. TLC results for all samples indicated a single spot with similar R_f values.

Example 9: UV Stability Studies of Forms I, II, and III

[0265] Samples of Forms I, II and III were exposed to ultraviolet (UV) radiation for 7 or 14 days. A CAMAG universal UV Lampe applied radiation to the samples with setting of 254 mμ. NMR and IR results show no degradation of Forms I and II after 14 days. Similarly, Form III exhibits no degradation after 7 days as determined by NMR and IR. TLC results for all samples indicated a single spot with similar R_f values.

Example 10: pH Stability Studies of Forms I, II, and III

[0266] A slurry of Forms I, II and III were formed with water and the pH value adjusted to either 1.0, 4.0, 7.0, 10.0, and 13.2. The slurries were stored for 7 or 14 days,

and subsequently the solids were removed by filtration. Form I converted to Form II in all of the samples. NMR and IR results show Forms I and II did not degrade after 14 days in the varied pHs, and similarly HPLC results show about 98% purity or more for these samples. Form III also exhibited no degradation after 7 days according to NMR and IR results. HPLC tests show about 95% purity or more; however IR results show Form III converted to Form II over the 7-day test. TLC results for all samples indicated a single spot with similar R_f values.

Example 11: Compression Studies of Forms I, II, and III

[0267] Samples of Forms I, II and III were subjected to 3 tons of force using a Moore Hydraulic Press for about 90 minutes. The resultant tablet's mass, diameter and thickness were measured to determine the density. The tablets were also analyzed by NMR and IR. Form I transitioned to a composition of Form II with a density of 1.197 kg/m³. Form II did not exhibit a transition and had a final density of 1.001 kg/m³. Finally, Form III did not exhibit a transition and had a final density of 1.078 kg/m³.

Example 12: Process for Producing L-Ornithine Phenyl Acetate via an Acetate Intermediate

[0268] Dissolve 25 mg of L-ornithine HCl 5 vols of H₂O, and then add excess acetic acid (about 5 vols) to form a slurry. Subject the slurry to temperature cycling between 25° and 40° C every 4 hours for about 3 days. Add 1 equivalent of phenylacetic acid (with respect to L-ornithine) and stir for about 4-6 hrs (possibly heat). Use IPA as an anti-solvent, add enough to obtain a ratio of 70:30 (IPA:H₂O). Isolate by vacuum filtration and dry for about 4-8 hrs at 80 °C to remove any residual acetic acid.

CLAIMS

1. A composition comprising a crystalline form of L-ornithine phenyl acetate., wherein said crystalline form exhibits an X-ray powder diffraction pattern comprising at least three characteristic peaks, wherein said characteristic peaks are selected from the group consisting of approximately 6.0°, 13.9°, 14.8°, 17.1°, 17.8° and 24.1° 2 θ .

2. The composition of Claim 1, wherein said crystalline form exhibits an X-ray powder diffraction pattern comprising characteristic peaks at approximately 6.0°, 13.9°, 14.8°, 17.1°, 17.8° and 24.1° 2 θ .

3. The composition of any one of Claims 1-2, wherein said crystalline form has a melting point of about 202° C.

4. The composition of any one of Claims 1-3, wherein said crystalline form exhibits a single crystal X-ray crystallographic analysis with crystal parameters approximately equal to the following:

unit cell dimensions: $a=6.594(2)$ Å, $b=6.5448(18)$ Å, $c=31.632(8)$ Å, $\alpha=90^\circ$,
 $\beta=91.12(3)^\circ$, $\gamma=90^\circ$;

Crystal System: Monoclinic; and

Space Group: P2₁.

5. The composition of any one of Claims 1-4, wherein the said crystalline form is represented by the formula [C₅H₁₃N₂O₂][C₈H₇O₂].

6. A composition comprising a crystalline form of L-ornithine phenyl acetate, wherein said crystalline form exhibits an X-ray powder diffraction pattern comprising at least three characteristic peaks, wherein said characteristic peaks are selected from the group consisting of approximately 4.9°, 13.2°, 17.4°, 20.8° and 24.4° 2 θ .

7. The composition of Claim 6, wherein said crystalline form exhibits an X-ray powder diffraction pattern comprising characteristic peaks at approximately 4.9°, 13.2°, 17.4°, 20.8° and 24.4° 2 θ .

8. The composition of any one of Claims 6-7, wherein said crystalline form comprises water and/or ethanol molecules.

9. The composition of Claim 8, wherein said crystalline form comprises about 11% by weight of said molecules as determined by thermogravimetric analysis.

10. The composition of any one of Claims 6-9, wherein said crystalline form is characterized by differential scanning calorimetry as comprising an endotherm at about 35° C.

11. The composition of Claim 10, further comprising a melting point at about 203° C.

12. The composition of any one of Claims 6-11, wherein said crystalline form exhibits a single crystal X-ray crystallographic analysis with crystal parameters approximately equal to the following:

unit cell dimensions: $a=5.3652(4) \text{ \AA}$, $b=7.7136(6) \text{ \AA}$, $c=20.9602(18) \text{ \AA}$, $\alpha=90^\circ$, $\beta=94.986(6)^\circ$, $\gamma=90^\circ$;

Crystal System: Monoclinic; and

Space Group: $P2_1$.

13. The composition of any one of Claims 6-12, wherein the said crystalline form is represented by the formula $[\text{C}_5\text{H}_{13}\text{N}_2\text{O}_2][\text{C}_8\text{H}_7\text{O}_2]\text{EtOH}\cdot\text{H}_2\text{O}$.

14. A composition comprising a crystalline form of L-ornithine phenyl acetate, wherein said crystalline form exhibits an X-ray powder diffraction pattern comprising at least three characteristic peaks, wherein said characteristic peaks are selected from the group consisting of approximately 5.8°, 14.1°, 18.6°, 19.4°, 22.3° and 24.8° 2 θ .

15. The composition of Claims 14, wherein said crystalline form exhibits an X-ray powder diffraction pattern comprising characteristic peaks at approximately 5.8°, 14.1°, 18.6°, 19.4°, 22.3° and 24.8° 2 θ .

16. The composition of any one of Claims 14-15, wherein said crystalline form is characterized by differential scanning calorimetry as comprising an endotherm at about 40° C.

17. The composition of Claim 16, further comprising a melting point at about 203° C.

18. A composition comprising:

at least about 50% by weight of a crystalline form of L-ornithine phenyl acetate salt; and

at least about 0.01% by weight benzoic acid or a salt thereof.

19. The composition of Claim 18, wherein the composition comprises at least about 0.10% by weight benzoic acid or a salt thereof.

20. The composition of any one of Claims 18-19, wherein the composition comprises no more than 5% by weight benzoic acid or a salt thereof.

21. The composition of any one of Claims 18-19, wherein the composition comprises no more than 1% by weight benzoic acid or a salt thereof.

22. The composition of any one of Claims 18-21, wherein the composition further comprises at least 10 ppm silver.

23. The composition of any one of Claims 18-21, wherein the composition further comprises at least 20 ppm silver.

24. The composition of any one of Claims 18-21, wherein the composition further comprises at least 25 ppm silver.

25. The composition of any one of Claims 18-24, wherein the composition comprises no more than 600 ppm silver.

26. The composition of any one of Claims 22-24, wherein the composition comprises no more than 100 ppm silver.

27. The composition of any one of Claims 22-24, wherein the composition comprises no more than 65 ppm silver.

28. The composition of any one of Claims 22-27, wherein about 50 mg/mL of said composition in water is isotonic with body fluids.

29. The composition of Claim 28, wherein the isotonic solution has an osmolality in the range of about 280 to about 330 mOsm/kg.

30. The composition of any one of Claims 22-29, wherein the composition has a density in the range of about 1.1 to about 1.3 kg/m³.

31. A process for making L-ornithine phenyl acetate salt comprising:

intermixing an L-ornithine salt, a benzoate salt and a solvent to form an intermediate solution;

intermixing phenyl acetate with said intermediate solution; and

isolating a composition comprising at least 70% crystalline L-ornithine phenyl acetate by weight.

32. The process of Claim 31, further comprising removing at least a portion of a salt from said intermediate solution before intermixing the phenyl acetate, wherein said salt is not an L-ornithine salt.

33. The process of Claim 32, wherein the process further comprises adding hydrochloric acid before removing at least a portion of the salt.

34. The process of any one of Claims 31-32, wherein intermixing the L-ornithine, the benzoate salt and the solvent comprises:

dispersing the L-ornithine salt in water to form a first solution;

dispersing the benzoate salt in DMSO to form a second solution; and

intermixing said first solution and said second solution to form said solution.

35. The process of any one of Claims 31-34, wherein said composition comprises at least about 0.10% by weight benzoate salt.

36. The process of Claim 35, wherein said composition comprises no more than 5% by weight benzoate salt.

37. The process of Claim 36, wherein said composition comprises no more than 1% by weight benzoate salt.

38. The process of any one of Claims 31-37, wherein the L-ornithine salt is L-ornithine hydrochloride.

39. The process of any one of Claims 31-38, wherein the benzoate salt is silver benzoate.

40. The process of Claim 39, wherein said composition further comprises at least 10 ppm silver.

41. The process of Claim 40, wherein said composition comprises at least 20 ppm silver.

42. The process of Claim 41, wherein said composition comprises at least 25 ppm silver.

43. The process of any one of Claims 39-42, wherein said composition comprises no more than 600 ppm silver.

44. The process of Claim 43, wherein said composition comprises no more than 100 ppm silver.

45. The process of Claim 44, wherein the composition comprises no more than 65 ppm silver.

46. The process of any one of Claims 31-45, wherein the phenyl acetate is in an alkali metal salt.

47. The process of Claim 46, wherein the alkali metal salt is sodium phenyl acetate.

48. The process of Claim 47, wherein said composition comprises no more than 100 ppm sodium.

49. The process of Claim 48, wherein said composition comprises no more than 20 ppm sodium.

50. The process of any one of Claims 31-49, wherein the L-ornithine is in a halide salt.

51. The process of Claim 50, wherein the halide salt is L-ornithine hydrochloride.

52. The process of Claim 51, wherein the composition comprises no more than 0.1% by weight chloride.

53. The process of Claim 52, wherein the composition comprises no more than 0.01% by weight chloride.

54. A process for making L-ornithine phenyl acetate salt comprising:

increasing the pH value of a solution comprising an L-ornithine salt at least until an intermediate salt precipitates, wherein said intermediate salt is not an L-ornithine salt;
isolating the intermediate salt from said solution;
intermixing phenyl acetic acid with said solution; and
isolating L-ornithine phenyl acetate salt from said solution.

55. The process of Claim 54, wherein the pH value is increased to at least 8.0.

56. The process of Claim 55, wherein the pH value is increased to at least 9.0.

57. The process of any one of Claims 54-56, wherein increasing the pH value comprises adding a pH modifier selected from the group consisting of sodium hydroxide, potassium hydroxide, sodium methoxide, potassium t-butoxide, sodium carbonate, calcium carbonate, dibutylamine, tryptamine, sodium hydride, calcium hydride, butyllithium, ethylmagnesium bromide or combinations thereof.

58. A process for making L-ornithine phenyl acetate salt comprising:

intermixing an L-ornithine salt, silver phenyl acetate and a solvent to form a solution, wherein the L-ornithine salt is a halide salt; and
isolating L-ornithine phenyl acetate from said solution.

59. A method of compressing L-ornithine phenyl acetate, the method comprising applying pressure to a metastable form of L-ornithine phenyl acetate to induce a phase change, wherein the metastable form exhibits an X-ray powder diffraction pattern comprising at least three characteristic peaks, wherein said characteristic peaks are selected from the group consisting of approximately 4.9°, 17.4, 13.2°, 20.8° and 24.4° 2 θ .

60. The method of Claim 59, wherein the pressure is applied for about 1 second or less.

61. The method of Claim 59 or 60, wherein the pressure is at least about 500 psi.

62. The method of any one of Claims 59-61, wherein the phase change yields a composition having a density in the range of about 1.1 to about 1.3 kg/m³ after applying the pressure.

63. The method of any one of Claims 59-62, wherein the phase change yields a composition exhibiting an X-ray powder diffraction pattern comprising at least three characteristic peaks, wherein said characteristic peaks are selected from the group consisting of approximately 6.0°, 13.9°, 14.8°, 17.1°, 17.8° and 24.1° 2 θ .

64. A composition prepared according to the method of any one of Claims 59-63.

65. The method of Claim 58, wherein the halide salt is L-ornithine hydrochloride.

66. A crystalline form of L-ornithine phenyl acetate salt for use in the treatment of hyperammonemia, wherein said crystalline form exhibits an X-ray powder diffraction pattern having characteristic peaks at approximately 4.9°, 13.2°, 17.4°, 20.8° and 24.4° 2 θ .

67. A crystalline form of L-ornithine phenyl acetate salt for use in the treatment of hyperammonemia, wherein said crystalline form exhibits an X-ray powder diffraction pattern having characteristic peaks at approximately 6.0°, 13.9°, 14.8°, 17.1°, 17.8° and 24.1° 2 θ .

68. A crystalline form of L-ornithine phenyl acetate salt for use in the treatment of hyperammonemia, wherein said crystalline form exhibits an X-ray powder diffraction pattern having characteristic peaks at approximately 5.8°, 14.1°, 18.6°, 19.4°, 22.3° and 24.8° 2 θ .

69. A composition, comprising a combination of at least two crystalline forms of L-ornithine phenyl acetate salt for use in treating hyperammonemia in a subject, wherein said crystalline forms are selected from the group consisting of Form I, Form II, and Form III, wherein:

said Form I exhibits an X-ray powder diffraction pattern having characteristic peaks at approximately 4.9°, 13.2°, 17.4°, 20.8° and 24.4° 2θ;

said Form II exhibits an X-ray powder diffraction pattern having characteristic peaks at approximately 6.0°, 13.9°, 14.8°, 17.1°, 17.8° and 24.1° 2θ; and

said Form III exhibits an X-ray powder diffraction pattern having characteristic peaks at approximately 5.8°, 14.1°, 18.6°, 19.4°, 22.3° and 24.8° 2θ.

70. The composition of Claim 69, wherein said crystalline forms are Form I and Form II.

71. The composition of Claim 69, wherein said crystalline forms are Form I and Form III.

72. The composition of Claim 69, wherein said crystalline forms are Form II and Form II.

73. The composition of Claim 69, wherein said crystalline forms are Form I, Form II and Form III.

74. The composition of any one of Claims 69-73, wherein the composition is formulated for administration from 1 to 3 times daily.

75. The composition of any one of Claims 69-74, wherein the total amount of L-ornithine phenyl acetate is in the range of about 500 mg to about 50 g.

76. The composition of any one of Claims 69-75, wherein the subject has hepatic encephalopathy.

77. A method comprising dissolving a crystalline form of L-ornithine phenyl acetate salt in an aqueous or isotonic solution, wherein said crystalline form is selected from the group consisting of Form I, Form II, and Form III, wherein:

said Form I exhibits an X-ray powder diffraction pattern having characteristic peaks at approximately 4.9°, 13.2°, 17.4°, 20.8° and 24.4° 2θ;

said Form II exhibits an X-ray powder diffraction pattern having characteristic peaks at approximately 6.0°, 13.9°, 14.8°, 17.1°, 17.8° and 24.1° 2θ; and

said Form III exhibits an X-ray powder diffraction pattern having characteristic peaks at approximately 5.8°, 14.1°, 18.6°, 19.4°, 22.3° and 24.8° 2θ.

78. A pharmaceutical solution comprising a therapeutically effective amount of L-ornithine phenyl acetate, prepared by the method of Claim 77 for use in treating hyperammonemia in a subject.

79. The pharmaceutical solution of Claim 78, wherein the solution is equal or less than 500 mL.

80. The pharmaceutical solution of Claim 78 or 79, wherein the solution comprises at least about 25 mg/mL of L-ornithine phenyl acetate.

81. The pharmaceutical solution of any one of Claims 78-80, wherein the solution comprises at least about 40 mg/mL of L-ornithine phenyl acetate.

82. The pharmaceutical solution of any one of Claims 78-81, wherein the solution comprises no more than 300 mg/mL.

83. The pharmaceutical solution of any one of Claims 78-82, wherein the solution is isotonic with body fluid.